CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-235

THE SAN GORGONIO PASS, BANNING AND RELATED FAULTS

Riverside County, California

by

Jerome A. Treiman

September 27, 1994

TABLE OF CONTENTS

INTRODUCTION p.3

REGIONAL OVERVIEW AND SEISMICITY p.3

DISCUSSION OF INDIVIDUAL FAULTS p.9
- SAN GORGONIO PASS FAULT ZONE p.9
- BANNING FAULT ZONE p.19
- SAN ANDREAS FAULT (San Bernardino strand) p.25
- GANDY RANCH FAULT p.27
- GARNET HILL FAULT AND RELATED FAULTS ON ALTA MESA p.28
- BEAUMONT PLAIN FAULTS p.31
- MCINNES FAULT AND RELATED FAULTS OF BLOYD (1971) p.33
- "MILLARD CANYON GUARD STATION FAULT" p.34
- COX RANCH FAULT p.34
- WHITEWATER FAULT p.35
- SOUTH PASS FAULT p.35
- LAWRENCE FAULT, McMULLEN FAULT, RANGER STATION FAULT AND OTHER RELATED STRUCTURES p.36
- MISCELLANEOUS FAULTS PARALLEL TO SAN TIMOTEO CANYON p.37

NEOTECTONIC SUMMARY p.38

RECOMMENDATIONS FOR ZONING p.39

AERIAL PHOTOGRAPHS USED p.41

REFERENCES p.42

LIST OF FIGURES AND PLATES

Figure 1	Location map	p.3
Figure 2	Relations between faults and crustal blocks (from Matti and others, 1992, figure 6)	p.4
Figure 3	Fault index map	p.5
Figure 4	Seismicity	p.8
Figure 5	Detail of area southwest of Stubbe Canyon	p.15
Figure 6	Detail of abandoned Cottonwood Canyon fan	p.17

Plates Ia-Id	Previous work, El Casco to White Water quads
Plates IIa-IId	features from aerial photo and field reconnaissance
Plates IIIa-IIId	recommended Earthquake Fault Zones

INTRODUCTION

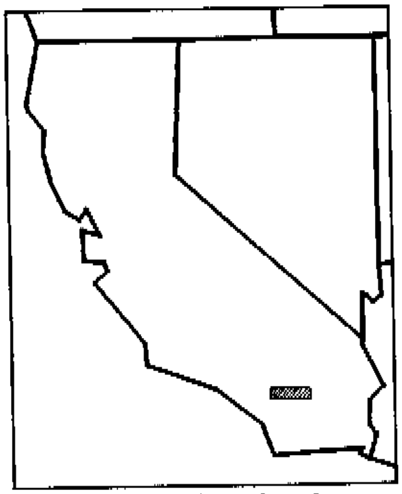


Figure 1. Location of study area.

The faults of the San Gorgonio Pass are part of a complex zone of faulting controlled by the San Andreas fault system as it attempts to accommodate the southern "Big Bend". The names "Banning Fault" and "San Andreas Fault" (various strands) have been applied to faults in this area in different ways, however, for this evaluation the nomenclature of Matti and others (1992) will be used for the regional faults (Figure 2). In the San Gorgonio Pass the Banning Fault is an older, but still partly active, strand of the San Andreas system. The San Gorgonio Pass Fault Zone is a more recently developed east-west trending complex of thrust and reverse faults which has been overprinted on the Banning fault and now lies largely south of that fault. It is part of the southern boundary of the Transverse Ranges as well as being associated with the San Andreas fault system. Several other faults, some directly associated with the San Gorgonio Pass and Banning faults, are also within the study area. The San Jacinto Fault Zone, in the El Casco quadrangle, was included in a previous fault evaluation (Kahle, 1987) and is not further addressed in this report.

The purpose of this study is to re-evaluate existing Earthquake Fault Zones within the San Gorgonio Pass (the San Andreas, San Gorgonio Pass, Banning, Gandy Ranch and Garnet Hill faults) and to determine if additional faults within this area are sufficiently active and well-defined to be included within new Earthquake Fault Zones under the Alquist-Priolo Earthquake Fault Zoning Act (Hart, 1994). The area evaluated includes the Beaumont, Cabazon, El Casco and White Water[1] 7.5-minute quadrangles (Figure 3). Earthquake Fault Zones currently exist on the El Casco quadrangle (CDMG, 1988), the Cabazon quadrangle (CDMG, 1974) and the White Water quadrangle (CDMG, 1980). The San Gorgonio Pass Fault was previously evaluated by Smith (1979). The Banning Fault was re-evaluated in the White Water quadrangle by Kahle and others (1987) following the 1986 North Palm Springs earthquake. The McInnes Fault was previously evaluated by Smith (1978).

REGIONAL OVERVIEW AND SEISMICITY

The San Andreas Fault Zone in southern California may be divided into two major elements, the **Mojave Desert segment** and the **Coachella Valley segment**, which step left from each other in the vicinity of the San Gorgonio Pass (Figure 2). In this stepover area (also referred to as the **San Bernardino Mountains segment** (Matti and others, 1992)) the fault zone becomes more complex and does not have a clear, currently active, throughgoing fault break. Instead it is a combination of older strike-slip faults (partly active or re-occupied) and newer thrust and tear faults. Allen (1957,p.337) recognized that "various structural complications make the continuity of the fault through this region doubtful." The San Gorgonio Pass area of the San Andreas Fault system (including the Banning and San Gorgonio Pass faults) has been discussed in some detail by Matti and others (1992).

The **Coachella Valley segment** of the San Andreas Fault Zone divides into two principal strands as it approaches the San Bernardino Mountains. The more northern of these has been called the **North Branch of the San Andreas Fault** (Dibblee, 1975), the **Mission Creek Fault** (Allen, 1957), and the **Coachella Valley segment of the San Andreas Fault** (Matti and others, 1992). This strand, or branch, goes through Desert Hot Springs and merges to the northwest into the **Mill Creek** and **Mission Creek** faults. The Mill Creek and Mission Creek Fault strands of the San Andreas system have apparently become less active as the faults in the San Gorgonio Pass have taken up more

[1] Early printings of this quadrangle were labeled "Whitewater" quadrangle, and therefore it is also spelled this way (one word) in some early references. The most recent printing is spelled "White Water" (two words) after the Post Office, however the river and certain other geographic features are spelled as one word.

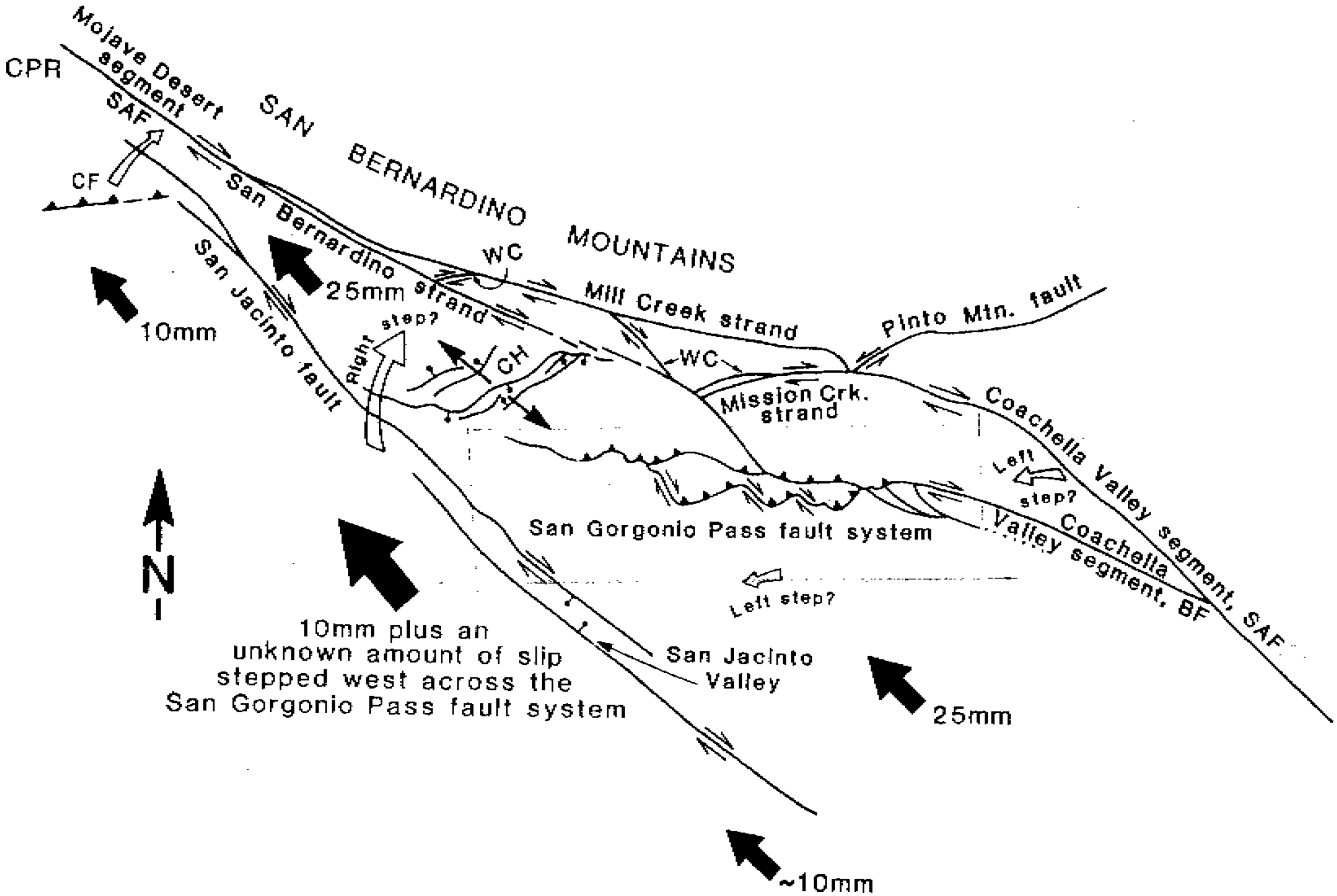


Figure 2 (FER-235) - Relations between faults and crustal blocks (from Matti and others, 1992, figure 6).--Schematic diagram illustrating relations between faults and crustal blocks in the vicinity of the south-central Transverse Ranges. Large solid arrows indicate the relative motion of crustal blocks; large hollow arrows indicate lateral transfer of slip. Small solid arrows indicate crustal extension in the Crafton Hills horst-and-graben complex. BF, Banning fault; CF, Cucamonga fault; CH, Crafton Hills; CPR, Cajon Pass region; SAF, San Sandreas fault; WC, Wilson Creek strand, San Andreas fault. Ten millimeters of annual slip on the San Jacinto fault is assumed from data of Sharp (1981).

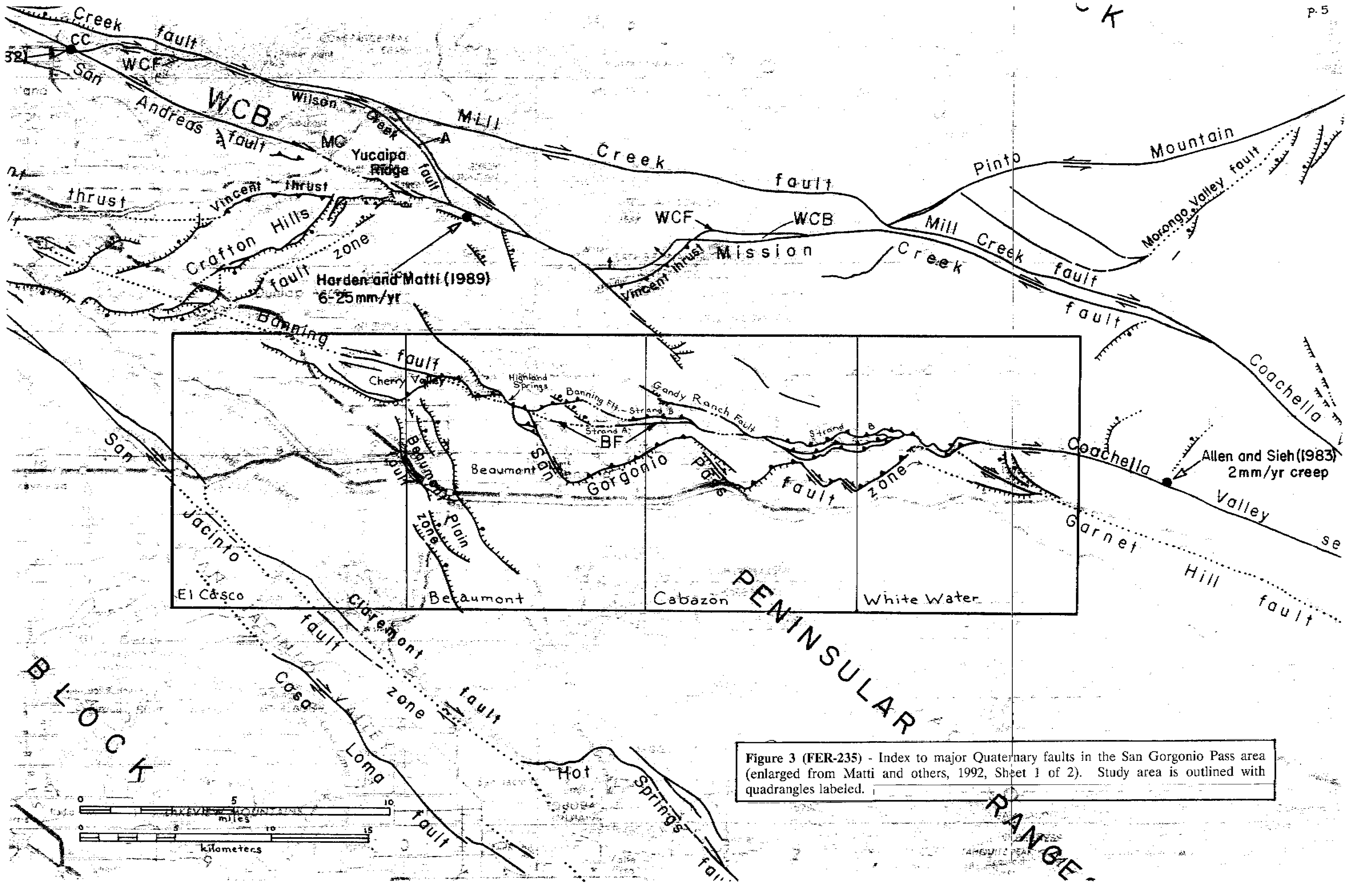


Figure 3 (FER-235) - Index to major Quaternary faults in the San Gorgonio Pass area (enlarged from Matti and others, 1992, Sheet 1 of 2). Study area is outlined with quadrangles labeled.

of the strain (Matti and others, 1992). The southern strand of the Coachella Valley segment has been called the **South Branch of the San Andreas Fault** (Dibblee, 1975), the **Banning Fault** (Allen, 1957), and the **Coachella Valley segment of the Banning Fault** (Matti and others, 1992). This segment veers westward as it goes into the San Gorgonio Pass. Allen and Sieh (1983) reported 2mm/yr of creep along this fault segment (Figure 3).

The **Mojave Desert segment** of the San Andreas Fault Zone has two principal strands at its southeastern end, where it merges into the San Bernardino Mountains area. The northern of these strands is the **Mill Creek Fault** (also considered part of the North Branch of the San Andreas by Dibblee, 1975). Matti and others (1992) believe that this strand is no longer an active part of the San Andreas Fault Zone, although it may have been locally reactivated by dip-slip movement. The southern, and currently active, strand is the **San Bernardino strand of the San Andreas** (part of the South Branch of the San Andreas of Dibblee, 1975) which appears to die out as it approaches the Banning Fault northeast of the town of Banning (Matti and others, 1992). To the northwest it has a slip-rate of 25 mm/yr (Rasmussen, 1982) or 6-25 mm/yr closer to this study area (Harden and Matti, 1989).

Within the San Gorgonio Pass area strain appears to be transferred, from the Coachella Valley segment to the Mojave Desert segment, in a very complex manner (Figure 2 is one interpretation from Matti and others, 1992). The change in strike of the fault system imposes a component of compression in addition to the strike slip displacement. These stresses are accommodated by displacement along the **San Gorgonio Pass Fault Zone** as well as the **Banning** and **Garnet Hill** faults. Matti and others (1992, p.1) estimate that about 3km of right-lateral displacement on the Banning Fault from the east "has been absorbed by convergence within the San Gorgonio Pass fault zone". Much of the strain is probably transferred in the central part of the Pass (near Cabazon) to the San Bernardino strand and some may be transferred, further west, to the San Jacinto Fault Zone. It has also been suggested that the San Andreas Fault may be continuous at depth through the region but is overlain by the south-verging thrust faults or by "mega-landslides". The complex interplay of faults has also resulted in extension across the **Beaumont Plain Fault Zone** and the **Crafton Hills Fault Zone** (northwest of, and not part of this study). Several other faults in the Pass area, that may be related to older periods of deformation, are also briefly discussed in this evaluation. Numerous other faults have been shown by Bloyd (1971); many of these have been defined or inferred based on groundwater data or limited exposure in aqueduct tunnels. These faults have been shown on Plates I a-d, for completeness, but only a few of these are discussed. The remainder of these inferred or buried structures have no indications of recent displacement. The study area and the principal faults assessed are identified on Figure 3.

Age Determination of Faulting

There are widespread Quaternary deposits in the faulted terrain in the San Gorgonio Pass. The recency of faulting can be judged based on which deposits are displaced and the nature and magnitude of that displacement. Much of the Quaternary stratigraphy was defined by Allen (1954 and 1957) with the latest Pleistocene and Holocene being further defined by McFadden (1982) and Matti and others (1992). Some of the alluvial chronology was based on comparison to fans along the Cucamonga Fault zone (Matti and others, 1982).

The oldest Quaternary unit of interest here is the San Timoteo Formation, a Plio-Pleistocene continental deposit which consists of sandstone, siltstone and conglomerate. Next oldest, in the Whitewater River area, are some deformed gravels mapped by Allen (1954, 1957). These gravels, along with the younger and more widespread Cabezon fanglomerate, are poorly sorted gravels consisting largely of granitic and pegmatitic rock. These units were mapped by Matti and others (1992) as undifferentiated Plio-Pleistocene sedimentary rocks and as dissected Pleistocene alluvial fan and flood plain deposits with a well-developed argillic horizon. Matti (personal communication, 1993) estimated that the dissected units may be on the order of 500,000 years old. The Heights fanglomerate is in places above the Cabezon fanglomerate, but is generally found more in the central and western part of the Pass whereas the Cabezon fanglomerate is found more in the eastern part of the Pass. The Heights fanglomerate is distinguished from the Cabezon fanglomerate by being dominated more by gneissic clasts rather than the granite and pegmatite clasts. Matti and others (1992) include this unit with late-Pleistocene older fan and flood plain deposits which have a moderately to well developed argillic horizon. All of these units are pre-Holocene.

The mid-Pleistocene to Holocene deposits, as mapped by Matti and Morton (1974-91, 1993) and Morton and Matti (1993a,b), have been subdivided into several distinct units (see Table 1). In most cases these latter units are dated relative to each other based on depositional relationships and on degree of soil development. A few radiocarbon ages have provided calibration for the relative age estimates. The late-Quaternary units listed in Table 1 are referenced (in parentheses) throughout the text.

TABLE 1
Relative ages of late-Quaternary map units (preliminary) used by Matti and Morton (1974-91, 1993) and Morton and Matti (1993a,b) [J.Matti, personal communication, 1993].

Qw	active channel deposits
Qfm	modern alluvial fan deposits
Qyf_5	late-Holocene fan deposits
Qyf_4	late-Holocene fan deposits (about 2.9ka per Sieh and Matti, 1992)
Qyf_3	mid-Holocene fan deposit (about 3.6-5ka per Sieh and Matti, 1992)
Qyf_2	early Holocene fan deposit
Qyf_1	late-Pleistocene to Holocene (?) fan deposit
Qof	late-Pleistocene fan deposits (20-250ka)
Qdf	mid-Pleistocene fan deposits (dissected) - (500ka); includes Heights and Cabezon fanglomerates of Allen (1957)

Seismicity

Seismicity in the San Gorgonio Pass area has been dominated in recent years by the 1986 North Palm Springs earthquake and its aftershocks (Figure 4). This M_L5.9 earthquake, located near the Mission Creek Fault, had a focal depth of 11.3 km and a focal mechanism for the main shock indicating pure strike slip on a plane trending N60°W and dipping 45° to 55° north (Jones and others, 1986). Sieh and Matti (1992) noted that the zone of seismicity as well as the focal mechanism for the mainshock project up to the Garnet Hill Fault rather than the Banning or San Andreas Faults. Matti and others (1992) noted "a deep wedge of seismicity" within the San Gorgonio Pass area (22km deep) that is bounded on the north by the Mission Creek Fault, on the south by the Banning Fault, and on the west by the southern end of the San Bernardino Strand of the San Andreas Fault. This is the deepest seismicity in southern California.

Recent work by Jones and others (1993 and written communication, 1993), based on relocation of historic earthquakes, suggests that there may be a throughgoing San Andreas Fault at depth which does not reach the surface as a simple trace. Their analysis of the relocated epicenters shows a 9km increase in depth of the base of seismicity southwest of a 30km long line which parallels and includes the focal plane of the North Palm Springs earthquake. This contrast implies a possible break between two different structural blocks. They infer that this break may be the San Andreas Fault or a structure splaying off from it.

Figure #4

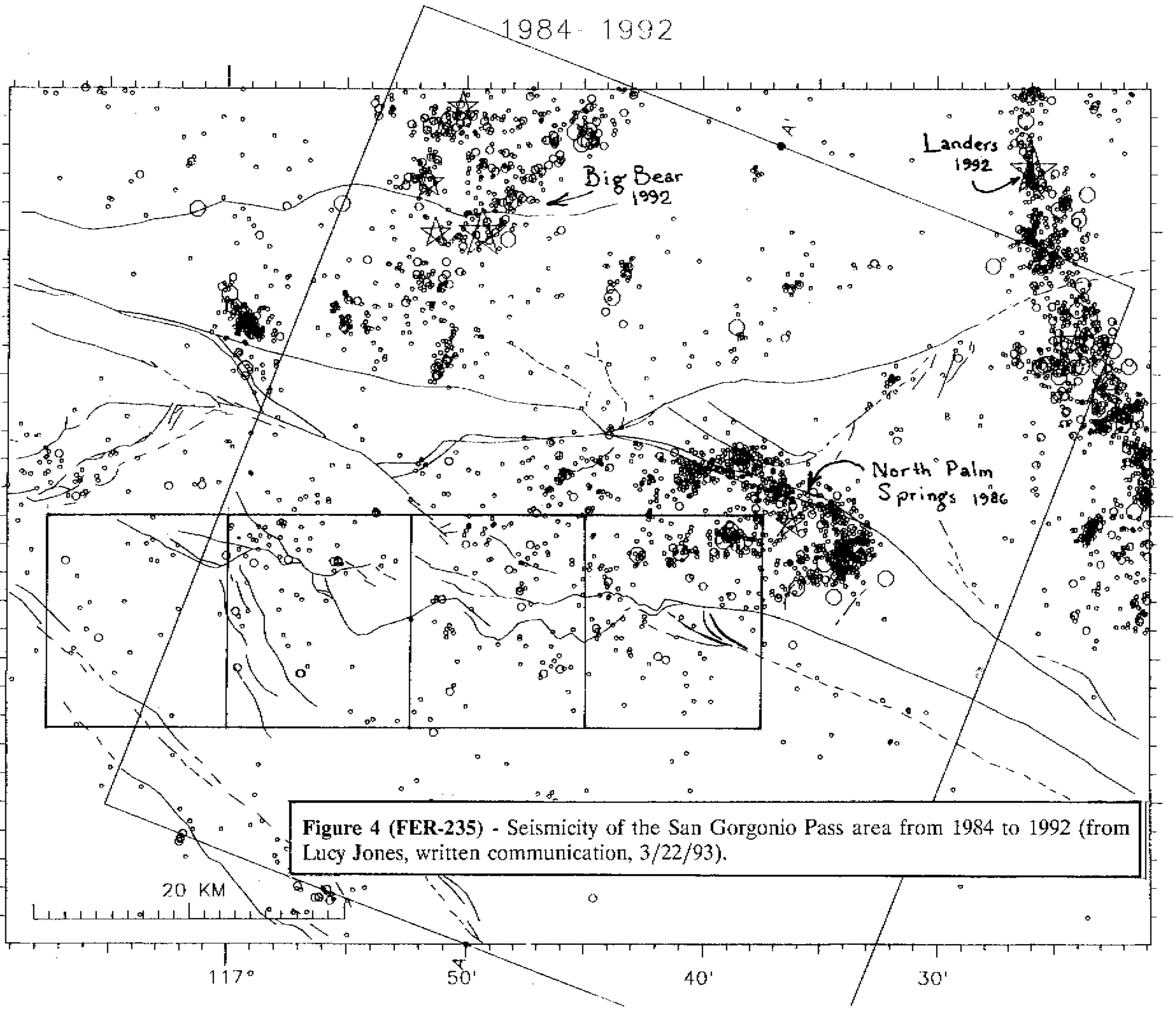


Figure 4 (FER-235) - Seismicity of the San Gorgonio Pass area from 1984 to 1992 (from Lucy Jones, written communication, 3/22/93).

DISCUSSION OF INDIVIDUAL FAULTS

Because of the number and complexity of faults addressed in this report, the faults will be individually discussed with regard to previous work, aerial photo and field observations and discussion. Recommendations for zoning of all of the assessed faults will be discussed under that final heading (p.39). Reference in the text to age of alluvial units is based on Table 1.

SAN GORGONIO PASS FAULT ZONE

Previous Work - (Plates I a,b,c & d)

The San Gorgonio Pass Fault is actually a zone of discontinuous reverse and thrust faults and associated tear faults. The older elements of this fault zone are superimposed on the Banning Fault Zone and are discussed under that heading (p.19). The younger strands of this zone lie outward (south) of the Banning Fault and the base of the San Bernardino Mountains (Figure 3; Plates Ia,b,c &d). The first portions of the San Gorgonio Pass Fault Zone to be recognized were the Cherry Valley Fault, a fault along the toe of the Banning Bench and a 2km-long northeast-trending segment crossing the lower part of the Millard Canyon fan on the Cabazon quadrangle (Vaughan, 1922; Shuler, 1953; Allen, 1957; Hope, 1969). The Millard Canyon fan part of the fault (on the Cabazon Quadrangle) was included in the initial Earthquake Fault Zones established in 1974 (CDMG, 1974; see Plate IIIc). Another segment of the fault zone was recognized to the east by Smith (1979) who was the first to apply the name to the fault zone (Plate Id). [A part of this fault was labeled Garnet Hill Fault by Morton and others (1987) but that name is here constrained to the strike-slip fault along the more prominent slope break just to the north]. Smith (1979) mapped a series of discontinuous south-facing scarps from about 1km west of the Whitewater River to about 5km west of the canyon. An Earthquake Fault Zone was also established around this portion of the fault zone based on Smith's work (CDMG, 1980; see Plate IIId). Matti and others (1985 & 1992) subsequently mapped a much greater extent to this fault zone and clarified its relation to the regional tectonics. Their work characterized the fault as a zone of northeasterly-trending thrust faults connected by northwesterly-trending tear faults.

Calimesa to Cherry Valley - Plates Ia and Ib

The western portion of the fault zone, from Calimesa to Cherry Valley, is considered the least active (Matti and others, 1992). On the El Casco quadrangle the two traces of the San Gorgonio Pass Fault mapped by Matti and Morton (1974-91) are largely the same as the two traces of the Cherry Valley Fault as mapped by Shuler (1953). The Cherry Valley Fault was mapped by Shuler (1953) as two sub-parallel normal faults which merge toward the east to form one trace (Plate Ia). He shows the fault zone juxtaposing terrace deposits (to the south) against San Timoteo Formation. Dibblee (1981a) shows this same relationship with a non-fault contact. Bloyd (1971) showed only one concealed trace, but in roughly the same location as Shuler's northern trace. Bloyd referred to the Cherry Valley Fault as a "postulated fault" based on groundwater data. Matti and Morton (1974-91) show two traces, similar to those shown by Shuler, but with more detail. They consider this to be the western part of the San Gorgonio Pass Fault Zone. This portion of the fault zone is called the San Gorgonio Pass Fault Zone (western extension) on the Preliminary Fault Activity Map of California (Jennings, 1992), and is indicated on that map to have had late Quaternary displacement (past 700,000 years).

West of Interstate 10 the fault has only very subdued geomorphic expression (as a subtle step in the remnants of an older surface). Although not found during earlier studies (Rasmussen & Associates, 1983), the southern trace was located in later trenching within the San Timoteo Formation (Dames and Moore, 1987; Rasmussen & Associates, 1988b). Dames and Moore found a zone of north-dipping reverse faults, including a fracture which appears (in their trench log) as if it may affect Quaternary soils (T3 located on Plate Ia). In a trench to the west (T2), the fault may be expressed in the San Timoteo Formation as a faulted anticline which has a steeper south limb (47° compared to 6° on the north limb). Rasmussen & Associates (1988b) made additional excavations and concluded that the fault was not active, based on the lack of deformation of late-Pleistocene alluvium.

Much of the surface expression of the southern fault trace, east of Interstate 10, was found to correspond to lithologic contacts rather than faults (ICG, Inc., 1990). Matti and Morton (1974-91) indicate that the southerly trace, immediately east of I-10, is marked by a south-facing scarp in a mid- to late-Pleistocene fan remnant (Qof and Qdf) and disappears west of Calimesa. They show it to the east, only to be partly truncated by a strand of the Beaumont Plain Fault Zone (see Plate Ib). Several investigations by consultants have provided very little new information on the southern trace.

Some faulting was found, however, near the northerly of the mapped traces (see Plate Ia for locations). In Calimesa a small northwest-trending fault was observed with about 12" normal separation (down to the southwest) of Pleistocene deposits (NW¼ of Sec.24, Rasmussen & Associates, 1987). Three to four southwest-dipping Pleistocene faults were observed in a pair of trenches about one mile to the southeast (SW¼ Sec.19 - Smith, 1988). A trenching study by ICG, Inc. (1990) relocated part of the fault in the northeast part of Sec.30 where they identified a fault in San Timoteo Formation marked by a colluvium-filled fissure. None of the consultants in these three studies considered the faults found to be active. The northern trace (as mapped by Matti and Morton, 1974-91 & 1993) merges locally with the southern trace near the quadrangle boundary, but then veers northeastward, displacing remnants of a mid- to late-Pleistocene fan (Qdf).

Cherry Valley to San Gorgonio River - Plate Ib

In the Cherry Valley area the fault takes on a more sinuous trace across the old fan of the Little San Gorgonio Creek. It is expressed as several discontinuous scarps on the older (mid-Pleistocene, Qdf) fan surfaces (Matti and Morton, 1993). In some places Holocene fan deposits are juxtaposed with mid-Pleistocene fan deposits (Qdf) across the fault, but the Holocene deposits are interpreted to have been deposited against a pre-existing scarp (J. Matti, personal communication, 1993). A study by Rasmussen & Associates (1992) across one of the more prominent scarps of the northern trace found evidence of faulting -- a thrust fault dipping north at 26°. Rasmussen judged the fault at this location to be pre-Holocene based on the lack of displacement of what he considered to be late-Pleistocene age alluvium that overlies the fault.

Eastward from Cherry Valley the San Gorgonio Pass Fault Zone apparently steps outward (southward) from the range front. The large topographic escarpment that extends eastward from Highland Springs (referred to hereafter as the Highland Springs scarp) may be largely the result of this fault. It is shown as a fault scarp by Matti and others (1992). [Other faults which may have contributed to the scarp include the Banning strand B to the east (see p.20), and possibly the "Wildwood Canyon" fault splay which extends to the northwest]. Matti and others (1992) mapped two additional scarps across a dissected Pleistocene fan remnant (Qdf) southeast of Highland Springs. The scarps are obscured by late-Pleistocene fan deposits (Qof). They then step the fault zone further south to define the toe of the Banning Bench. They infer the fault to step southward along northwest-trending, right-lateral tear faults (shown as concealed or inferred faults on Plate Ib).

Blanck (1987) mapped an east-west trending thrust fault, 1½ miles southeast of Highland Springs, that he projects eastward across the southern part of the Banning Bench. Rasmussen & Associates (1979a) also investigated this area but did not identify faulting as shown by Blanck, although they did identify a fault within the San Timoteo Formation where Blanck mapped the head of a landslide. This fault, trending N79°E, does not displace Heights Fanglomerate. Rasmussen & Associates (1979b) found another fault, in Section 32, which also trends N79°E, dips generally steeply north, and does displace Heights Fanglomerate (late-Pleistocene). Fractures and displacement extended into dark-brown older alluvium and offset the base of the soil less than 0.5 foot.

Allen (1957) and Dibblee (1981b) both mapped a concealed fault at the toe of the Banning Bench (not shown on maps in this report). This fault was investigated by Rasmussen & Associates (1989a) who interpreted trench data to indicate that the fault exists at the base of the slope but is overlain by unfaulted late-Pleistocene to Holocene sediments. However, in one trench late-Pleistocene deposits were clearly faulted, and younger unfaulted sediments were not radiocarbon-dated. Thus, the age of faulting is uncertain. The fault was observed with dips ranging from 36° to 57° to the north. About one-half mile to the east (north of Gilman St.) Matti and Morton (1993) show the fault cutting early Holocene fan deposits (Qyf_2?). Blanck (1987) also mapped several thrust faults along the toe of the Banning Bench. Blanck's thrust faults are mapped somewhat above the base of slope, whereas Matti and Morton (1993) mapped their fault at the base of the slope. The youngest unit that Blanck (1987) shows faulted is older alluvium and he infers the fault beneath younger fan deposits.

San Gorgonio River to Millard Canyon - Plate Ic

Across the head of the San Gorgonio River fan the fault zone consists of discontinuous scarps. Soils on this fan surface, where it is cut by the scarp, are considered Holocene by Matti (personal communication, 1993). From Hathaway Creek to Potrero Creek the fault zone is largely obscured by modern fan deposits. Multiple discontinuous scarps extend southeasterly across remnants of early to mid-Holocene deposits (of the Potrero Creek fan (Morton and Matti, 1993a), but there has been little other information developed for this area.

Morton and Matti (1993a) show the fault to swing back northeasterly across the Millard Canyon fan as a complex scarp and monoclinal warp in mid- to late-Holocene fan sediments (Qyf_3 and Oyf_4). This fault segment was previously mapped by Allen (1957) and Hope (1969). Several consulting reports address this scarp, in part because this stretch of fault is within an Earthquake Fault Zone (Clopine, 1988, 1989a, 1989c, & 1990; Rasmussen & Associates, 1994). Two of the consulting reports (Clopine Geological Services, 1989c & 1990) investigated part of the northwest trending segments (not previously zoned) and documented a significant strike-slip component. The report by Rasmussen & Associates (1994) records several parallel north-dipping thrust faults. The other two reports (Clopine Geological Services, 1988 & 1989a) documented thrust displacements along the northeasterly trending section of the fault. The displaced sediments were judged to be Holocene based on previous mapping and the lack of soil development, significant weathering or lithification. Additional detailed mapping along the northeast-trending thrust has been done by Morton and Matti (1993a) and students at California Institute of Technology (unpublished work in progress, personal communication from Dr. Kerry Sieh, 1992). These studies have documented a young fault scarp up to 2.2m high with additional monoclinal warping above the scarp. Sieh and Matti (1992) provide considerable detail on this fault segment: total vertical displacement of the fan surface (Qyf_3) reaches a maximum of 13 meters, the largest scarp contains more than one fault plane with dips as low as 20°, and the youngest scarp (with roughly 1m of vertical displacement) is in alluvium that is roughly 2,875 years old (Qyf_4). [Some of this data comes from unpublished trenching studies by John Tinsley and John Matti of the US Geological Survey].

Millard Canyon to Stubbe Canyon - Plates Ic and Id

East of the Millard Canyon fan the fault is very poorly defined but is inferred to mark the abrupt lobate southern front of the mountains (Dibblee, 1981b&c; Matti and others 1992). Between Deep Canyon and Stubbe Canyon landsliding and recent alluviation may be obscuring the exact fault location, although Sieh (personal communication, 1993) believes that a scarp may be visible in fan deposits just southeast of Deep Canyon. Morton and Matti (1993a) map this scarp as an erosional scarp between modern stream and fan deposits (Qfm) and Qyf_4. East of Lion Canyon, Allen (1957) mapped a large landslide complex at the mountain front (Sections 2 & 11). The landsliding is easily suggested by a closed depression and breached basin behind a lobate front. Matti and others (1992) mapped more extensive landsliding in this area (not shown on plates herein) but interpret the fault to pass through this area as well. Sieh (1992, personal communication) has a different interpretation - he attributes the apparent closed basins to backtilting related to an upward-steepening thrust fault and observed a possible 0.5m-scarp near the eastern end of this lobe (Plate Id). In any of these interpretations the surface trace of the fault may be largely concealed by landsliding or slumping of the oversteepened front.

A northeast-trending scarp at the mouth of Stubbe Canyon was attributed by Allen (1957) to a normal fault related to the Banning Fault Zone, however this scarp also coincides with the San Gorgonio Pass Fault as mapped by Matti and others (1992). This scarp is in what Matti and others (1992; Morton and Matti, 1993b) map as Holocene fan deposits (Qyf_3), and is overlain by modern fan deposits (Qfm).

East of Stubbe Canyon - Plate Id

East of Stubbe Canyon the San Gorgonio Pass Fault Zone may have two active zones: one along the base of the hills and one which has stepped southward to the distal portion of the Cottonwood Canyon fan. The entire group of thrusts at the base of the hills is roughly coincident with the Banning Fault, although the lower traces appear to be identified as the easternmost part of the San Gorgonio Pass Fault Zone by Matti and others (1992). The higher members of this group are discussed with the Banning Fault (p.20). The zone at the base of the hills does not show up with any clarity on the mapping in progress by Morton and Matti (1993b) but it is suggested by Matti and others (1992) to continue close to the mountain front as a low-angle thrust which steepens and merges, east of Cottonwood Canyon, with the Banning Fault. A portion of this fault, immediately west of Cottonwood Canyon, has been mapped by Rich Wolf (unpublished mapping in progress, CalTech, September 1993; see Plate Id). One short segment across a low ridge west of the mouth of Cottonwood Canyon (shown by Morton and Matti, 1993b; also by Wolf), was investigated by Rasmussen & Associates (1984b, southern trench site) who found no evidence of faulting at this location. Rasmussen's trench data suggests that this low ridge is an eroded remnant of a late-Pleistocene fan.

Smith (1979) mapped and named an element of the San Gorgonio Pass Fault Zone that lies about 1.5 miles south of the Banning Fault, and which appears to merge (near White Water) with the Garnet Hill Fault. Smith's fault, interpreted as a thrust, is based on a discontinuous scarp in alluvial fan deposits which was mostly 1m high but up to 2m high and with a scarp angle up to 35°. Some mapped scarp segments may represent "a rather localized monocline along which surface rupture did not occur" (Smith, 1979, p.3). Where the fault is inferred he observed broad warping. This east-west alignment of scarps was called the Garnet Hill Fault by Morton and others (1987) but is here considered more closely related to the San Gorgonio Pass Fault Zone. [I am restricting the Garnet Hill Fault to the strike- slip fault at the base of the hill to the northeast and associate the apparent thrust fault with the San Gorgonio Pass Fault Zone]. A trench study by Lohr (1983) across some of the scarps did not find any faults. He interpreted the scarps as probable erosional or depositional features. Hart (1983) suggested, however, that the trench logs may support monoclinal warping due to a buried fault. The San Gorgonio Pass Fault has not been mapped further east than about three-quarters of a mile west of the Whitewater River. On the fan of Cottonwood Creek, a short northeast-trending fault has also been shown by Wolf (unpublished mapping in progress, CalTech, September 1993) between the frontal faulting and the faulting to the south. This fault truncates remnants of an older (late-Pleistocene) alluvial fan (Qof).

Aerial Photo Interpretation and Field Observation - (Plates II a,b,c & d)

Calimesa to Cherry Valley - Plates IIa and IIb

West of Interstate 10 the San Gorgonio Pass Fault Zone (Cherry Valley Fault) has only weak expression as a subtle step or broad escarpment across remnants of an older, now eroded surface (Qof). Southeast of Calimesa the southern mapped trace of the fault is characterized by similar remnants of a step in the older surface. The scarp indicated by Matti and Morton (1974-91) across late Pleistocene deposits is irregular and probably dissected. The northern trace is barely suggested by a few possibly deflected (right-lateral) ridges and one deflected drainage. A subdued scarp (about 11° in Pleistocene deposits, Qdf) is visible near the common border of the El Casco and Beaumont quadrangles, as mapped by Matti and others (1992). Where this feature is apparently sharpest (based on aerial photos), as a southeast-facing slope north of Vineland on the Beaumont quadrangle, it may have merely been enhanced by lateral erosion of minor local drainages. The scarp shown by Matti and Morton (1993) north of Orchard Ave. at Nancy Ave. is a broad feature (in Qdf) which could be a local warp or an old channel margin instead of a well-defined scarp. Their southern trace, at Woodland Ave. appears to mark the southern margin of a gentle domal landform which could be tectonic. In general, the drainages which cross these fault segments show no convincing lateral displacement or indications of renewed incision due to uplift.

Cherry Valley to San Gorgonio River - Plate IIb

In the Cherry Valley area the fault zone is only discontinuously expressed in older (mid to late Pleistocene) fan remnants (Qdf) and is largely masked by the younger late-Pleistocene (Qof) to Holocene (Qyf) alluvial fans. West of Little San Gorgonio Creek is a locally abrupt scarp across Pleistocene deposits (Qdf). This scarp has been modified, in places, by stream erosion and grading, but there are a few natural appearing slopes as steep as 15° or greater. The fault was not apparent in a road cut on the east side of Little San Gorgonio Creek and its expression here is very indistinct. A steeper slope (probably modified by erosion) in fan deposits just west of Noble Creek marks a buttress unconformity where early-Holocene fan deposits (Qyf_2) appear to be deposited against a scarp in Pleistocene deposits (Qdf). East of Noble Creek the fault steps to the southeast where two additional fault-scarps are quite prominent in the older fan remnants, but are buried by late-Pleistocene to early Holocene deposits (Qyf_1). [The main break in slope 1500' to the north is a possible splay of the Banning Fault and is discussed on p.20].

East and southeast from Highland Springs there are several inferred fault strands. The Highland Springs scarp is largely buried by younger fan deposits but a partially dissected scarp remnant, as steep as 18°, is visible at its western end. [The scarp may have been artificially steepened by agricultural activity]. Above the scarp is an elevated late-Pleistocene fan deposit (Qof). Two much smaller scarps to the south are discontinuously expressed on remnants of an older mid-Pleistocene fan deposit (Qdf), similar to the scarps to the northwest, and have slope angles of 10° or less. These scarps also are being buried by late-Pleistocene fans (Qof). A short north-south fault scarp segment shown by Matti and Morton (1993), adjacent to Smith Creek, was not visible in a crudely stratified boulder to cobble conglomerate exposed in an erosion gully that cuts across its trend. This mapped scarp segment may be an erosional channel margin instead. There are no geomorphic or outcrop indications of faulting as shown by Blanck (1987) along the southern margin of Sections 36 and 31, nor along his fault's eastward extent across the Banning Bench. Thrust faulting appears to step to the southeast (to the southern margin of the Banning Bench) along a concealed northwest-trending tear fault, as inferred by Matti and Morton (1993; refer to Plate Ib). This inferred tear fault has no exposure or youthful expression.

The uplift of the Banning Bench provides dramatic evidence of faulting along the San Gorgonio Pass Fault Zone with slightly greater uplift at the southern margin. Both the ground elevation and the dissection of the southern margin is indicative of this uplift, and remnants of now-breached closed basins are evident to the immediate north. Older fan deposits on the Banning Bench and in the town of Banning (Qof, estimated here to be about 50,000 to 80,000 years old per John Matti, personal communication, 1993) would appear to be offset vertically on the order of 70-80m, based on map interpretation. However, if there has been any recent displacement, at least along the western part of this scarp, it has been obscured by subsequent alluviation and no fresh features are visible in the photos or in the field. A recent cut slope in Heights fanglomerate (Qdf) has exposed a possible shear or fault dipping 20° to 25° north. Less than one mile to the east a faceted spur (23° slope angle) and offset ridges and drainages (near the small cemetery in the western part of Section 4) suggest that there may have been more recent displacement along this more easterly part of the southern margin of the Banning Bench. The more extensive erosion above this slope also suggests greater uplift. A low narrow bench at the eastern edge of the Beaumont quadrangle, discernible in the 1936 air photos (but now obscured by development), may indicate a fault scarp -- a possible continuation of the scarp mapped to the northeast by Morton and Matti (1993a). This latter scarp, as visible today, is rather broad (one to two blocks wide) but nevertheless apparent in Qyf_3. The breadth of the feature may be the result of more than one fault trace and/or warping, similar to the warping west of Millard Canyon. The scarp is truncated by a late Holocene fan (Qyf_4 or Qyf_5) of the San Gorgonio River, but continues to the east (see next section). A more abrupt, east-west trending scarp is visible in the field, about one to two blocks to the south, and is also truncated by the younger fan.

None of the faults shown by Blanck (1987) across the south frontal slope of the Banning Bench are visible in the aerial photos. No attempt was made to verify these faults in the field. Faults on top of the Banning Bench, south of the Banning Fault, have been mapped by Blanck (1987; discussed above) and by Rasmussen & Associates (1979a,b). The faults of Rasmussen are very weakly expressed: the northern fault by a possibly right-deflected ridge to the east (but no deflected drainages) and the southern fault by a limited north-facing scarp at its western end (within Qdf).

San Gorgonio River to Millard Canyon - Plate IIc

This segment of the fault zone is very similar to the segment to the west in that it has a weak and discontinuously expressed western portion which then steps southeast to a more prominent and continuous thrust fault. Although the magnitude of vertical displacement is much less here (due to the younger age of the offset surface), the slip rate appears to be greater (see discussion, p.16), and here there are younger, clearer scarps and good evidence of Holocene displacement. The faults mapped by Morton and Matti (1993a) are generally well expressed geomorphically, although some of the concealed segments and connections are open to interpretation.

A probable fault scarp in Holocene fan deposits (Qyf_3) was observed northeast of the San Gorgonio River. This scarp is the apparent northwest continuation of the broader scarp observed on the west side of the modern drainage (described above). A large sand and gravel pit in the younger Holocene deposits of the San Gorgonio River revealed no obvious deformation or offset of the coarse alluvial fan deposits (as viewed through binoculars from the southwest side of the pit). However, due to the coarse nature of the deposits and local sloughing displacement of the crudely stratified fan deposits cannot be precluded. Other subtler scarps are visible east of the mouth of Hathaway Creek (Section 35). These back-facing scarps may indicate lateral spreading.

Approaching Potrero Creek, evidence of active faulting within the San Gorgonio Pass Fault Zone swings southeastward. Several discontinuous southwest-facing scarps are visible on early Holocene fan remnants ($Qyf_{1\,\&\,2}$) of Potrero Creek. These 1 to 3 meter-high scarps have slope angles of 10° to 13°. Several of these scarps are irregular and dissected. Most are buried by the mid-Holocene Qyf_3.

Several east-west oriented scarps are also visible on the Potrero Creek fan (east of the creek). The highest of these scarps, up to 5m high and up to 15° angle, is within Qyf_1 fan deposits and appears to be buried by younger fans. A few smaller scarps displace Qyf_2 and Qyf_3. Other east-west scarp-like features and lineaments interpreted from the aerial photos appear to be involved with property lines and field margins or else mark the possibly fault-bounded margins of outliers that are now being buried by the alluvial fans.

The most continuous scarp is also the youngest -- it parallels the freeway and then swings northeast across the Millard Canyon fan (Qyf_3). Aerial photo and on-the-ground mapping confirm the location and configuration of the fault essentially as shown by Morton and Matti (1993a). The scarp angle is commonly 20° and locally steeper in cobbly material. The rounded crest of the scarp is supportive of both warping and possibly multiple displacement events. The northeast portion of this scarp is the highest as well as the broadest. This fault displaces all but the youngest Holocene fans (Qyf_5) and the modern wash deposits.

Millard Canyon to Stubbe Canyon - Plates IIc and IId

Eastward from Millard Canyon the location of the fault is suggested in general by the lobate front of the hills, and locally in detail by several discontinuous scarps. Just east of the modern wash of Millard Canyon (west-central part of Section 4) there appears to be a remnant of an east-west trending scarp (in Qyf_4) as mapped by Morton and Matti (1993a). A narrow linear bar and channel adjacent to a faceted spur in the southeastern part of Section 4 may be fault related, although stream erosion is a more likely explanation in this location. Sieh (personal communication, 1993) suggests that a locally irregular margin of a limited fan deposit (Qyf_4) immediately to the southeast (southwest corner of Section 3) may reflect faulting. An erosional explanation is also possible for this feature. If this is a fault it is not present in the young Holocene fan (Qyf_5) of Lion Canyon.

Further east, east of Lion Canyon, a closed depression and breached basin (Sections 2 & 11) suggest landsliding, however the source for such a landslide is not apparent. There appears to be less landslide mass below the depressions than in the adjacent areas. This suggests that the depressions and corresponding "mass deficits" downhill reflect pre-existing drainages rather than a landslide with associated grabens. Geomorphically the terrain here supports Sieh's hypothesis of a backtilted thrust toe with some gravity-failure of the oversteepened front. The geology of the area complicates this interpretation, somewhat (see discussion on p.16). At the eastern edge of this lobe the Cabezon fanglomerate is tilted steeply to moderately to the south (80° shallowing southward to 40°), with an intraformational unconformity indicating that this tilting was going on during Cabezon deposition. The dip suggests tilting in the opposite direction from that suggested by the geomorphology. A possible scarp at up to 25° was visible in the field along one part of this front, with a gentler bevel above (22°) suggesting multiple displacements.

The next lobe to the east (Section 1) also has some faceted slopes (27°) on three adjacent spurs. Set out from the base of slope is a fairly continuous scarp, very similar to the one mapped by Sieh two lobes to the west. In this instance, however, the scarp appears to continue across a small canyon fan in a manner that does not look like erosion (see Figure 5). A previously zoned

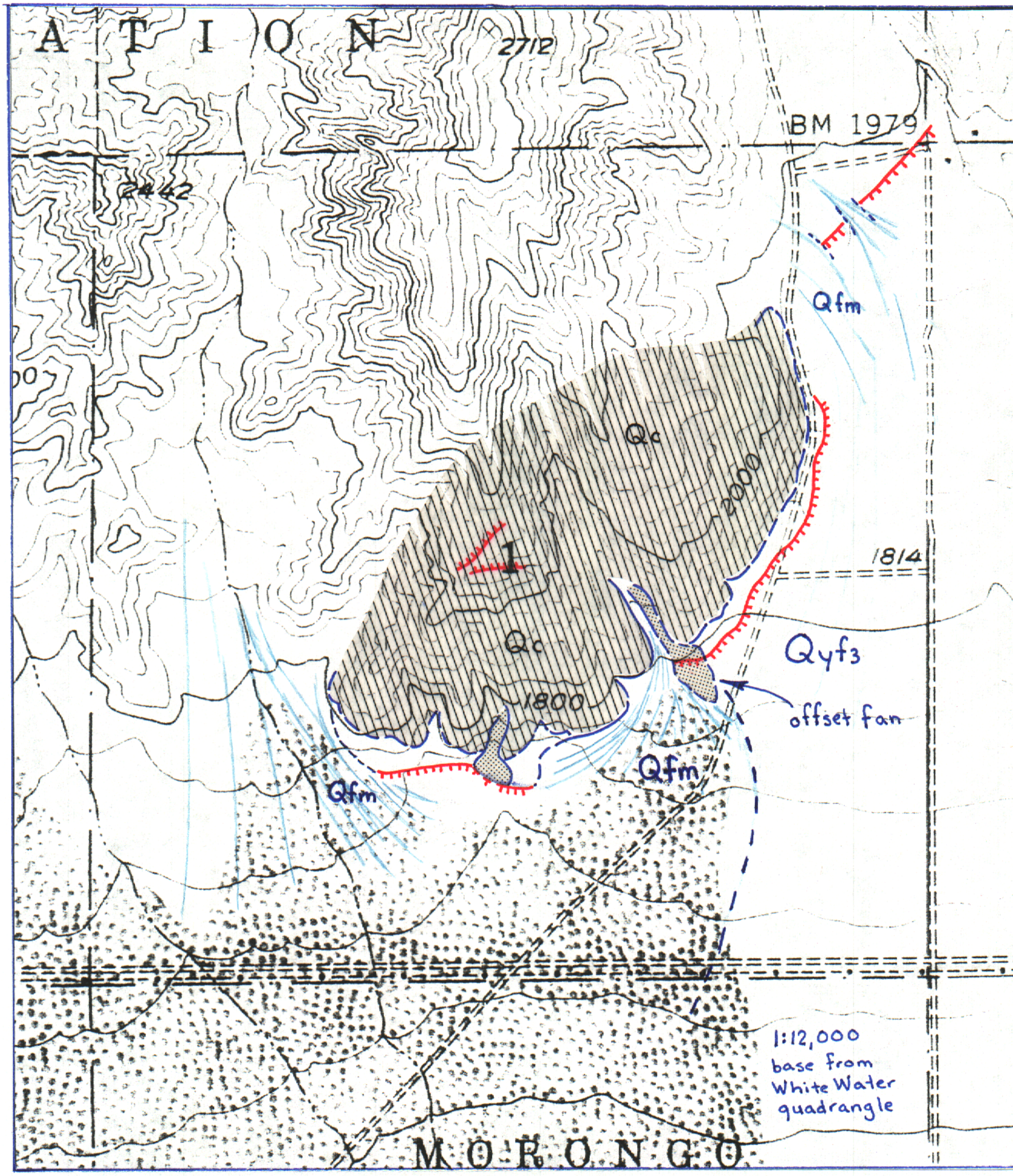


Figure 5 (FER-235) - Detail of area southwest of Stubbe Canyon showing fault scarps in Holocene alluvium. Qc is Cabezon conglomerate. Qyf_3 is mid-Holocene fan. Qfm is modern alluvial fan. Note small offset fan (shaded) that is younger than Qyf_3. [*based on aerial photo interpretation of Riverside Co. Flood Control photos from 12/19/58, frames 13 & 14; geology based on Morton and Matti (1993b)*]

northwest-trending fault along the spine of this lobe is probably controlling a linear drainage, but has no fresh looking characteristics. A northeast-trending fault has also been mapped across this lobe following two aligned canyons that appear to be fault-line features, although discontinuous northwest-facing scarps suggest a backthrust or other thrust-related faulting is operating within the upper block. A scarp across the fan of Stubbe Canyon is aligned with this mapped fault. The scarp in Stubbe Canyon faces southeast and is within Holocene fan deposits, but has been cut or overlain by very recent alluvium.

East of Stubbe Canyon - Plate IId

Eastward from Stubbe Canyon the San Gorgonio Pass Fault Zone may be expressed along two zones: one along the base of the hills and one which has stepped southward. The zone at the base of the hills continues from the scarp in Stubbe Canyon but is only intermittently expressed, being largely obscured by very young fan deposits (Qfm). It is best expressed by a pair of parallel scarps in the northwest corner of Section 5 (adjacent to a dirt road) where a northeast-trending ridge has shielded the fault from being obscured by the youngest alluvial deposits. Immediately to the east (at the north edge of Section 5), the break in slope at the back edge of a remnant of older fan deposits is not as abrupt as other suspected fault breaks. As discussed earlier, trench data suggest that there is no fault at the break in slope as mapped by others. There are, however, other subtle scarp-like features trending east-southeast (north and south of the dirt road shown in the northern part of Section 5) which might suggest a projection or stepover to the Garnet Hill Fault. Higher faults in this zone are indistinguishable from the faults of the Banning Fault Zone and are discussed under that heading (p.20).

South of the hills are two areas of probable thrust faulting attributed to the San Gorgonio Pass Fault Zone. One is in the western part of Section 5 where two scarp segments mark the faulted front of a late-Pleistocene fan (Qof, see Figure 6). This fan would appear to have emanated from a now landslide-dammed segment of Cottonwood Canyon, and thus pre-dates the modern fan of this canyon. A broad erosional trench along the axis of this old fan must have been cut by the Cottonwood drainage (prior to the redirection of that drainage) in response to uplift along the fault. A subtle scarp across this inset trench, observed parallel to and southeast of the road here, may be manmade but faulting is nevertheless suggested by a short scarp visible in pre-grading photography. The erosional trench is being filled again (since beheadment of its drainage) by a younger and smaller fan deposit (Qfm) that has a vegetational lineament aligned with the scarp. The second area of probable faulting is indicated by a fault scarp, as mapped by Smith (1979), that is still partly visible to the south on the younger fan ($Qyf_?$) of Cottonwood Canyon (Section 8). I could confirm an approximately 1m scarp with a slope angle of 8°-12°. The continuation of this, or a related scarp is readily visible in older fans to the east (Sections 9 & 10). The scarp visible at the mouth of the Whitewater River and its extension eastward, south of Whitewater Hill, may be related to this fault zone. This latter extension (mapped as the inferred trace of the Garnet Hill Fault) is obscured by erosion and landsliding.

<u>Discussion and Conclusions</u>

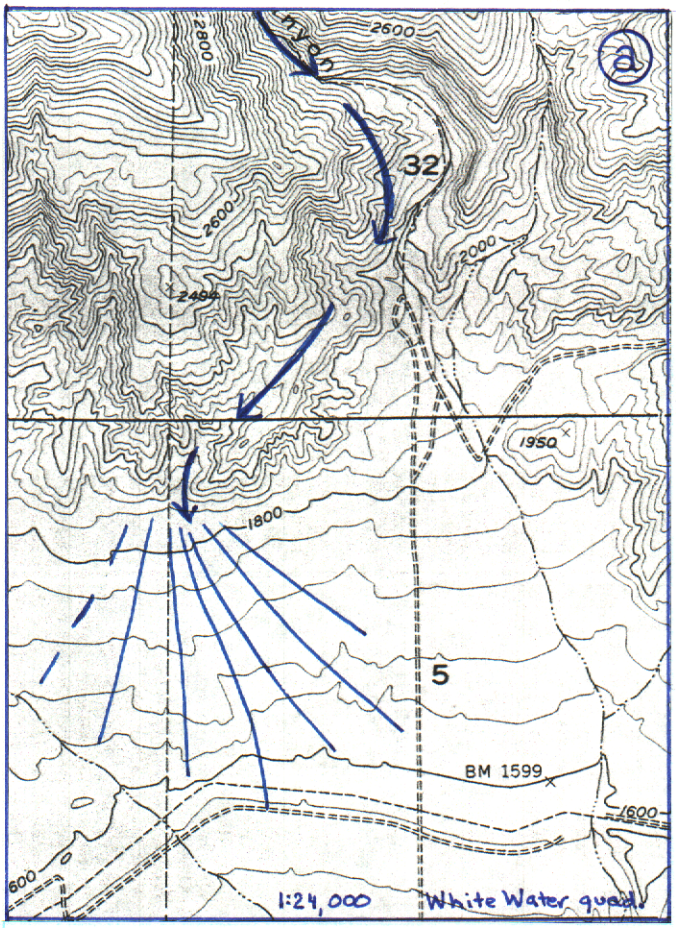
Calimesa to Cherry Valley -

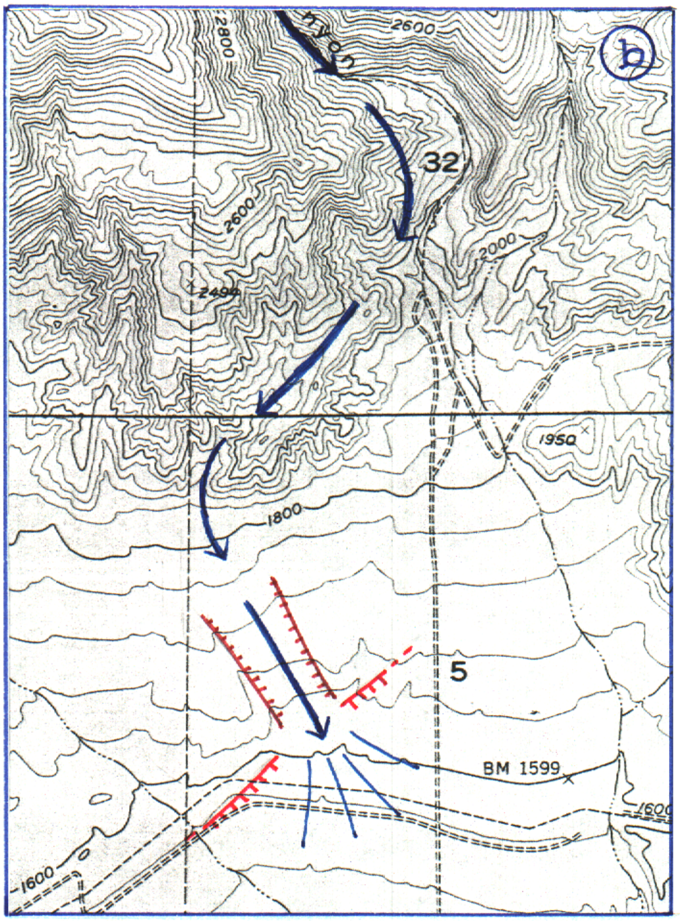
The Cherry Valley Fault (western San Gorgonio Pass Fault Zone) is weakly expressed geomorphically and shows no evidence of Holocene activity. Two traces have been mapped but each one has only been confirmed in separate areas - the southern trace to the west of Interstate 10 and the northern trace to the east. Although there is some suggestion of right-lateral deflections along the trace of the fault southeast of Calimesa, none of these deflections are very convincing and ridges that should be offset are not. The subtle scarps near the quadrangle boundary are only visible in Pleistocene deposits and are not distinct enough, without corroborative evidence, to be indicative of Holocene displacement.

Cherry Valley to San Gorgonio River -

The San Gorgonio Pass Fault Zone in Cherry Valley through Highland Springs does not appear to be active. The fault zone is only expressed in remnants of older, Pleistocene fans. The scarps are consistently obscured by Holocene fans and have no obvious effect on modern drainages. This relationship is supported by limited subsurface investigations.

Faults and fault scarps at the southern margin of the Banning Bench separate Holocene alluvial units from San Timoteo Formation in the uplifted Banning Bench and would appear to be at the western limit of active faulting. Uplift of late-Pleistocene deposits (Qof) suggest a vertical slip-rate of 0.9-1.6mm/yr. Scarps, facets and stream offsets strongly suggest recency. The faults as





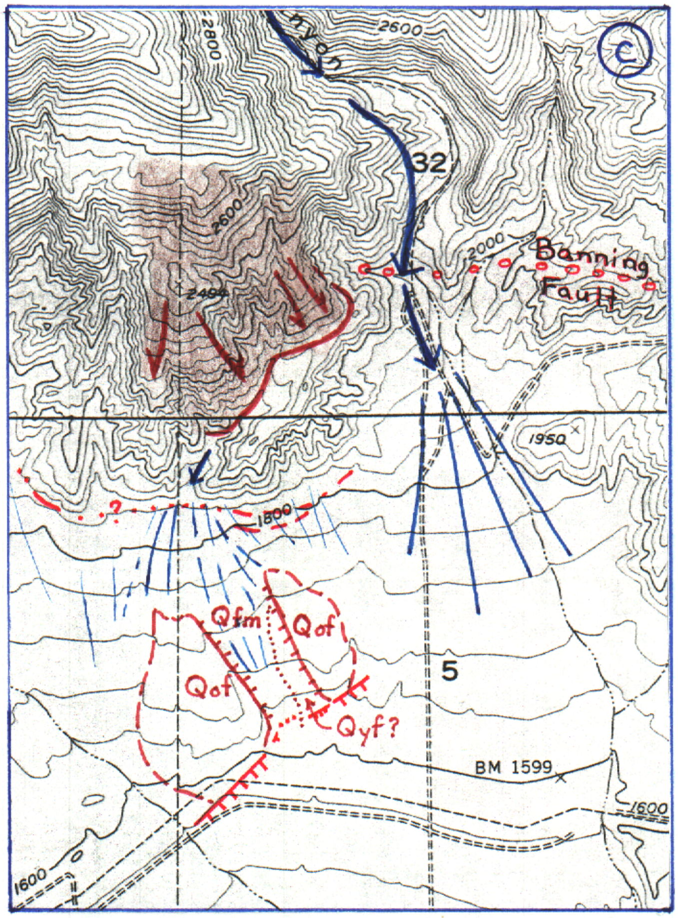


Figure 6 (FER-235) - Detail of abandoned Cottonwood Canyon fan showing sequence of faulting and drainage diversion. [*based on aerial photo interpretation of USDA photos AXM-12K-129 to -131*]

a Late-Pleistocene Cottonwood Canyon drains southwesterly from mountain front.

b Faulting outboard of mountain front causes incision of fan (Qof) by Cottonwood Creek (Qyf?).

c Landslides dam drainage and cause diversion of Cottonwood Creek to present alignment. Faulting at mountain front has elevated beheaded drainage and caused additional incision of Cottonwood Canyon. Young fan (Qfm) from beheaded drainage is starting to fill trough in old fan. Outboard fault has had some activity, displacing inset fan (Qyf?) and is visible as a tonal lineament in modern fan (Qfm). Banning Fault may have displaced beheaded drainage right-laterally.

shown by Blanck (1987) probably exist within the San Timoteo Formation but are not evident as Holocene features. Faults on the Banning Bench surface do not display any evidence of recency. A fault at the south margin of Section 32 was observed to displace a dark-brown soil which the consultant felt might be Holocene, however there is no clear geomorphic expression of this fault on a surface which appears rather stable and should better preserve such features.

San Gorgonio River to Millard Canyon -

This section of the fault zone is apparently active based on several scarp segments in Holocene alluvial fans. Fault expression is notable at and east of Potrero Creek. This is roughly where the San Andreas Fault sweeps southward into the Pass and probably reflects the introduction of stress from that fault zone. The larger displacement of Qyf_3 across the Millard fan suggests a vertical slip-rate of about 2.6-3.6mm/yr, whereas the smaller (1m) displacement of Qyf_4 yields a minimum slip rate of only 0.3mm/yr. There are three possible explanations for this discrepancy: a) the slip rate has been less in the last 2,875 years than previously (or conversely there was "a burst of tectonic activity between 5,000 and 2,875" years ago (Sieh and Matti, 1992)), b) the last event occurred more recently than the age of Qyf_4, or c) we are nearing the end of the recurrence interval for this fault and a pending event will make up the slip-deficit. If 1-meter events are typical, then alternative c) is still inadequate to make up the higher slip-rate based on Qyf_3. The truth may lie in a combination of all three explanations.

Millard Canyon to Stubbe Canyon -

This segment of the fault zone, although ambiguous in detail, has created a lobate mountain front and has clearly ponded Holocene sediments behind an uplifted thrust toe along the central lobe. The fault trace at this lobe is obscured by slumping of the oversteepened scarp, but is probably very near the base of the slope. South-dipping bedding of the Cabezon fanglomerate suggests that this area was folded above a blind thrust before the fault finally broke up to the surface. Landsliding seems to be a less likely interpretation for this landform, based on the south-tilted strata and a lack of corresponding landslide mass below the two depressions. Faceted spurs and possible scarps in alluvium at the two flanking lobes suggest that there may be two parallel faults - one at the toe of the slope and one 200-300 feet out from the base of slope. A north-northwest trending fault, west of Stubbe Canyon (through Section 1), that was mapped by Allen (1957) shows no indication of Holocene activity.

Stubbe Canyon to Whitewater River -

At Stubbe Canyon the fault is clearly active, with a prominent scarp across the Holocene fan. Eastward the fault is not as clear, but appears to be active along two fronts. At the base of the hills a probable Holocene scarp is only seen in one or two remnants where faulting is in close proximity to the Banning Fault. In fact, as far as nomenclature is concerned, the faults here seem inseparable. Another zone of active thrust faulting has stepped outward onto the distal portion of the Holocene fan of Cottonwood Canyon and extends eastward to the Whitewater River, and maybe beyond. The intermediate northeast-trending fault in Section 5 would also appear to be active if the photo-interpreted features are real.

Summary -

The San Gorgonio Pass Fault Zone is a zone of Quaternary reverse, thrust and wrench faults which extends from the Whitewater River to Calimesa, and perhaps beyond. From the Banning Bench, eastward, there is evidence for Holocene displacement, principally as scarps across Holocene alluvial fans. The age of the fans is largely inferred, but limited radiocarbon dating has confirmed faulting within the past 3000 years in at least one locality. The most active portion appears to be between the San Andreas Fault at Potrero Creek and the Banning and Garnet Hill faults east of Cottonwood Canyon. Referring to the eastern portion of the fault zone, Smith (1979) suggested that "most of the near-surface offset along this fault is accommodated by bending of the poorly consolidated alluvial strata, and that rupture extends all the way to the surface during only some events and for only part of the fault trace." The portion of this fault zone west of the Banning Bench shows no indication of Holocene activity. Matti and others (1992,p.24) stated, however, that "future ground ruptures throughout the entire extent of the ... zone cannot be ruled out".

BANNING FAULT ZONE

Previous Work - (Plates I a,b,c & d)

The Banning Fault can be inferred for over 100km, from the Indio Hills to the San Jacinto Fault. The elements of the Banning Fault in the eastern part of the San Gorgonio Pass were first identified by Vaughan (1922). The name "Banning Fault" was introduced by Hill (1928). Work by Allen (1957) and more recently by Matti and others (1992) has clarified our understanding of the fault zone as we know it today. During late Cenozoic time the Banning Fault was principally a right-lateral fault which had as much as 16 to 25km of displacement, but it has since responded mainly to and been obscured by compressional tectonics in the Pass while continuing as a strike-slip fault only to the east.

Matti and others (1992) divided the Banning Fault into three parts: the western, central and eastern segments. It is principally the central, or San Gorgonio Pass segment, which is addressed in this evaluation. Along most of its length this fault dips steeply north, placing crystalline rocks on the north against late Cenozoic sedimentary rocks on the south. This segment "largely is obscured by Quaternary sedimentary deposits, and has been modified by Quaternary reverse, thrust, and wrench faults of the San Gorgonio Pass fault zone" (Matti and others, 1992, p.19). Between Cherry Valley and Cottonwood Canyon this segment was mapped by Matti and Morton (1982) as consisting of two parallel traces (Strand A and B), and so should perhaps be referred to as a fault zone. The more northerly of these traces (Strand B) is believed by Matti (personal communication, 1993) to be an early trace of the San Gorgonio Pass Fault Zone. Portions of Strand A as well show compressional influences and only a few short segments of the strike-slip Banning Fault are still evident. Although much of Strand A and B may be kinematically associated with the San Gorgonio Pass Fault Zone they are discussed in this section because of their geographic and historic association with the Banning Fault. The eastern segment of the Banning Fault, which extends east from the Whitewater River out of the study area, has displaced Quaternary gravels of the Whitewater River 2-3km right-laterally. All of the traces of this fault zone from Millard Canyon eastward are currently included in an Alquist-Priolo Earthquake Fault Zone (CDMG, 1974 & 1980). The current zones are based largely on Allen (1957). Allen's fault traces are not plotted directly on Plates Ic and Id but are represented as replotted on the modern base by CDMG (1974 & 1980).

Calimesa to Cherry Valley - Plates Ia and Ib

The westernmost portion of the Banning Fault exposed within the study area is in the northeastern part of the El Casco quadrangle and the northwestern part of the Beaumont quadrangle. The fault in this area consists of one prominent high-angle trace which separates Pleistocene San Timoteo Formation (or "gray fanglomerate") on the south from granitic rock to the north (Dibblee, 1981a; Matti and others, 1992). Displacement is indicated as strike-slip by Matti and others (1992). The westernmost exposure of the fault was at the boundary between Ranges 1 and 2 West. A study in this area by Schaefer Dixon Associates (1990) investigated the fault and found no evidence of the fault where it had been previously mapped [evidently based on Shuler, 1953]. A subsequent study by Rasmussen & Associates (1990) found an approximately 65°N-dipping fault about 800' south of where it had been previously mapped (but essentially where mapped by Matti and Morton, 1974-91). Rasmussen judged the fault at this locality to be inactive because it appeared to be buried by Pleistocene alluvium and it had no geomorphic expression. The Banning Fault has been inferred to the west in various locations, based on groundwater (e.g. Bloyd, 1971) and on gravity data (Willingham, 1981) but is not exposed in this direction.

A recent study to the east (Section 20), by Woodward-Clyde Consultants (1993), has found evidence for Holocene displacement west of Cherry Valley. They found several near-vertical fractures that penetrate what appear to be Holocene deposits above the bedrock trace of the Banning Fault (Rockwell, 1993). Although the magnitude of displacement was not determined there was evidence, from striae and mullion in the gouge zone, of lateral movement. Right-lateral drainage offsets were also observed. Eastward through Cherry Valley the fault is concealed and is inferred based on groundwater data.

Woodward-Clyde (1993) also looked at an east-west trending fault that had been mapped by Shuler (1953) south of the Banning fault. They termed this fault the upper Singleton Canyon Fault. It is apparently based on the linearity of the canyon and no evidence for it was found in the studies by Woodward-Clyde [based on enhanced roadcut exposures, trenches, mapping and refraction seismic surveys].

Wildwood Canyon splay of the Banning fault - Plate Ib

A fault coming in to the study area from the northwest joins the Banning Fault at Highland Springs (Matti and Morton, 1993). Little is known about this unnamed fault in the northern Cherry Valley area (Beaumont 7½' quadrangle) and the upper drainage area of Wildwood Canyon (Forest Falls 7½' quadrangle). It was shown by Dibblee (1957-58) along with a shorter subparallel fault along a canyon to the west. [A later map by Dibblee (1981b) shows only the more continuous fault.] The fault apparently trends into the map area from the northwest where Matti and others (1992) indicate the fault is characterized by a northeast-facing scarp in late-Pleistocene to Holocene alluvial fan deposits. Within the study area the scarp in mid-Pleistocene fans (Qdf) faces northeast and then southwest as it crosses Little San Gorgonio Creek. East of Noble Creek the fault is mapped along the base of the hills where it becomes concealed by late-Pleistocene (Oof) and Holocene (Qyf_2) fan deposits. It may have contributed to the Highland Springs scarp.

A trenching study by Medall et al (1979) investigated the main fault just north of the study area (across the San Bernardino County line) and found that it did not displace late-Pleistocene alluvium estimated to be about 100,000 years old. Rasmussen & Associates (1988a) inferred that the short fault to the southwest was similarly pre-Holocene.

Cherry Valley to Millard Canyon - Plates Ib and Ic

The Banning Fault is again prominent east from Highland Springs. From this point eastward to Cottonwood Creek the fault zone commonly consists of at least two distinct traces. Matti and Morton (1982) referred to these as Strands A and B. The southern trace only (Strand A) was initially shown by Allen (1957) as far east as Millard Canyon. Later mapping by Dibblee (1981b), Blanck (1987) and Matti and others (1985 & 1992) identified additional fault traces associated with the Banning Fault in the vicinity of the Banning Bench. Where Strand A passes under the Banning Bench it does not displace the Quaternary Heights fanglomerate, according to Allen (1957), although Blanck (1987) portrays the fault as cutting this unit. Matti and others (1992) show this strand concealed by a mid-Pleistocene unit (Qdf).

Strand B is probably an early strand of the San Gorgonio Pass Fault Zone (which has since shifted its locus of activity southward)(John Matti, personal communication, 1993). It has a distinct south-facing scarp across the Banning Bench (offsetting Qdf and Qof). The Highland Springs scarp is about five times the height of the scarp on the Banning Bench and is probably a composite scarp, constructed by movement first on Strand B and later by movement on the San Gorgonio Pass Fault zone. A much more subtle northwest-trending zone of northeast-facing *en echelon* scarps appears to cross the buried southern trace (A) but may be offset by the northern trace (B) as mapped by Matti and Morton (1993). Blanck (1987) interpreted the Banning Fault to be cut off at depth by the San Gorgonio Pass Fault in the Beaumont quadrangle but he felt this was not so further to the east.

East of the San Gorgonio River, Strands A and B have been mapped parallel to each other with a topographic trough between. Strand A juxtaposes Pliocene Hathaway Formation on the south with crystalline basement rocks on the north. Strand B (ancestral San Gorgonio Pass Fault) is mapped by Morton and Matti (1993a) as a thrust fault within the basement rocks and appears to overlap the southern trace as these faults approach Potrero Creek.

A single trace (probably the younger thrust) is mapped east of Potrero Creek to Millard Canyon where it merges with or truncates faults trending into it from the northwest (the San Andreas Fault and the Gandy Ranch Fault). Sieh and Matti (1992) describe a south-facing scarp in mid- to late-Holocene alluvium (Qyf_3, about 3,600 years old) at Millard Canyon. The right-lateral component of displacement is roughly 5m with about 3m of reverse displacement (K.Sieh, personal communication, 1993).

Millard Canyon to Cottonwood Canyon - Plates Ic and Id

The fault is mapped on the east side of Millard Canyon as a north-dipping thrust or reverse fault with a component of lateral displacement (of Heights fanglomerate) that is about three times the vertical (data cited by Sieh and Matti, 1992 from unpublished work in preparation). As many as four overlapping and sinuous thrust or reverse faults are mapped eastward from Millard Canyon to Cottonwood Creek (Allen, 1957; Dibblee, 1981b,c; Matti and others, 1992). In the western part of the White Water quadrangle these faults again delimit a prominent east-west trough with map relationships suggesting that the more northerly traces have overridden the southern traces east of Stubbe Canyon, although these relationships are far from clear. This complex zone of thrust faults seems to demonstrate a strong overprint on a pre-existing Banning Fault by early elements of the San Gorgonio Pass Fault Zone.

From Stubbe Canyon to Cottonwood Canyon the fault zone lies near, and partly defines, the mountain front. The lowermost thrust fault is discussed as part of the San Gorgonio Pass Fault Zone (see p.11, p.16, p.18). Large landslides partly obscure the faulting. Rasmussen and Reeder (1986) interpret some of the low-angle thrusts of Matti and others (1992) to be landslide related and imply that a higher-angle fault (about 60° or greater) is buried in this vicinity. They described a trench exposure immediately west of Cottonwood Canyon which showed a nearly horizontal slip surface that they attribute to landsliding. The trench log (from Rasmussen & Associates, 1984b) shows very fractured metamorphic rock thrust over silty-sand. They believe that the Banning Fault either merges with or is truncated by the San Andreas Fault at Cottonwood Canyon. Another trench to the south by Rasmussen & Associates (1984b), across a prominent break in slope, found no evidence of faulting in the crudely layered silty-sand with gravel of an older alluvial fan remnant (Qof).

Cottonwood Canyon to Painted Hill - Plate Id

In contrast to the low-angle to flat-lying faults mapped west of Cottonwood Canyon, the Banning Fault to the east is a fairly linear strike-slip fault which dips north at 35° to 65° (Allen, 1957; Matti and other, 1992; Morton and others, 1987; Rasmussen and Reeder, 1986). [This is considered the San Andreas Fault by Rasmussen and Reeder (1986)]. Matti and others (1985 & 1992) suggest that Whitewater River gravels (estimated to be at least 500 to 750 ka by Sieh and Matti, 1992) have been displaced 2-3km right-laterally along the Banning Fault to their present position on the hill west of White Water (Whitewater benchmark). A simple single trace dips 40° to the north in the Whitewater River canyon and a prominent groundwater barrier attests to its effect on the Holocene alluvium. Clark (1984) mapped several short, discontinuous, but parallel features at the eastern margin of the White Water quadrangle which may indicate recent movement along the fault zone. The fault continues eastward, beyond the limits of this study, where Holocene displacement has been previously documented (Kahle and others, 1987). Soil and Testing Engineers (1986) found drainage channels offset right-laterally (pre-historic) as much as 200 feet in their study just east of the quadrangle boundary.

As a result of the 1986 North Palm Springs earthquake some minor cracking occurred along the fault within the study area, north of Alta Mesa (Whitewater Hill of Allen, 1957) and also south of Painted Hill; cumulative right-lateral displacement of up to 7.2cm occurred further east (Kahle and others, 1987). Sharp and others (1986), in contrast, argued that there was negligible lateral displacement and referred to the surface cracks as "trace fracturing".

<u>Aerial Photo Interpretation and Field Observation</u> - (Plates II a,b,c & d)

Calimesa to Cherry Valley - Plates IIa and IIb

There is no surface indication of the Banning Fault to the west of Calimesa. The fault is well expressed to the east by cliffs, erosional differences and linear drainages for about two miles along the boundary between basement rocks and San Timoteo Formation, but is not evident at the surface where overlain by late-Pleistocene and Holocene fan deposits. Geomorphic expression has been largely assumed to be fault-line topography resulting from the contrasting strength of the two bedrock units. There is one 3/4-mile stretch of fault, however, where more youthful features appear. Numerous right-laterally deflected drainages and ridges accompany two closely parallel fault traces with a possibly downdropped block between. This zone appears to be at a right-step between two strands of the fault. This well-expressed part of the fault zone is in the El Casco quadrangle. A short distance to the east, in the Beaumont quadrangle, the fault's proximity is indicated by near vertical dips in the San Timoteo Formation and a general break in the topography, but within another ½-mile the fault is entirely obscured by late-Pleistocene fan deposits.

The Singleton Canyon Fault, in the El Casco quadrangle, was field checked where it was mapped by Shuler (1953) immediately west of Singleton Road. Grading (probably for a pipeline) exposed a buttress unconformity within the San Timoteo Formation, but no indication of faulting. A distinct tonal/vegetational contrast near the east end of the lineament has no topographic expression and is probably related to bedding in the San Timoteo Formation.

Wildwood Canyon splay of the Banning fault - Plate IIb

At the northern margin of the quadrangle this fault splay, and its shorter companion to the southwest, are defined by a series of aligned canyons, saddles and slope breaks, but the shorter trace has no expression across the Pleistocene fan of Little San Gorgonio Creek. The main trace, however, is identified by a northeast-facing scarp west of the creek and a southwest-facing scarp to the east. Only the northeast-facing scarp looks sharp, probably reflecting erosional enhancement. The remainder of the scarp is obscured wherever it is crossed by Holocene deposits. A steep-appearing scarp northwest of Highland Springs is probably modified by artificial fill over the top of the slope.

Cherry Valley to Millard Canyon - Plates IIb and IIc

The Banning Fault has no expression across Cherry Valley, but becomes apparent east of Highland Springs. Strand A of Matti and Morton (1982) has no geomorphic expression until east of San Gorgonio River, but Strand B has a prominent 15° scarp across the late-Pleistocene surface (Qdf & Qof) of the Banning Bench. The scarp angle may have been accentuated by the road at the base of the slope and leveling of the field at the top of the slope. Strand B also may also have contributed to the height of the Highland Springs scarp, but it has no obvious effect on the intervening dissected crystalline basement terrain. A set of *en echelon* northwest-trending scarps is very subdued across the Pleistocene surface of the Banning Bench and is probably older than Strand B. Strands A and B cross the divide between San Gorgonio River and Mias Canyon with subdued, erosionally modified slope breaks.

Eastward from Mias Canyon, almost to Potrero Creek, both traces of the Banning Fault have prominent topographic expression where they mark the northern and southern margins of an east-west trough. Hathaway Creek, which crosses this structure and may be an antecedent drainage, shows no lateral offset. Strand A is marked by a few north-facing scarps, but in general it is not clearly expressed except as the southern trough margin. Based on outcrop pattern, this southern trace appears to be a high angle reverse fault. Strand B appears younger, based on its sharper topographic expression and its apparent overlap of Strand A, ½-mile west of Potrero Creek. This northern strand is marked by an eroded escarpment and several hanging valleys. Although Strand B has strong topographic expression, this may be in part due to the greater strength of the granitic and metamorphic rocks to the north relative to more highly sheared rocks in the trough area. This apparent escarpment may be older than it appears. This is suggested by the fact that the nickpoint of several of the drainages crossing this break have had time to migrate upstream, eroding their way in fairly competent crystalline rock. The strength of the rock is indicated by the remaining slopes between the cross-cutting drainages. There are no nickpoints evident at the fault trace location.

Just west of Potrero Creek, where Strand B overlaps A and defines the southern margin of the hills, a hillside bench was observed. This bench appears to consist of an elevated remnant of colluvial or fan deposits, and the outcrop pattern in the aerial photos suggests a low-angle thrust (as mapped by Morton and Matti, 1993a) within the scarp and perhaps a higher-angle fault at the base of the slope. There has been no age estimate made of these deposits, but the scarp looks sharper and steeper than any other features to the west along the Banning Fault. One part of this slope is beveled with a lower scarp steeper than 30° and an upper scarp at about 20° (angles estimated from ground photographs) suggesting at least two displacement events along this trace. Neither Strand A or B is exposed or expressed topographically across the Potrero Creek drainage. A fault across Potrero Creek is suggested, however, by a stand of trees upstream of the faults projection.

East of Potrero Creek the Banning Fault (Strand B?) is marked by a lobate line of oversteepened slopes, a pattern suggesting a relatively low-angle thrust fault. It is joined by the Gandy Ranch Fault and/or San Andreas Fault just before the combined fault zone creates a marked scarp across the upper portion of the Millard Canyon fan. The scarp crosses Holocene fan surfaces of two different ages (Qyf_3 and Qyf_4), with a scarp angle of up to 25°. The scarp on the older fan is higher than on the younger fan, indicating at least two Holocene events. The scarp on the younger fan is not as sharp which may suggest that the fan was relatively unconsolidated when it was displaced. The fault is also indicated at Millard Canyon by springs and lush vegetation at and upstream of the fault. A greater proportion of boulders (relative to smaller clasts) in the modern stream at this point indicates a higher energy stream segment which may also indicate recent activity.

Although the first impression is that Strand B overlaps A west of Potrero Creek, small outliers in Sections 36 and 31, and a larger outlier in the SE quarter of Section 31 and the NE quarter of Section 6, suggest remnants of a buried trough which may be offset from the trough to the west (rather than being overlapped by Strand B). This interpretation would be in accord with Allen's (1957) original mapping which showed a northwest-trending fault offsetting the Banning Fault. There is no other indication of this inferred cross-cutting fault. The inferred offset Strand A is buried by Holocene fans and has no expression across the Millard Canyon fan.

Millard Canyon to Cottonwood Canyon - Plates IIc and IId

The Banning Fault Zone is not obvious in detail for about three to four miles eastward from Millard Canyon. The general location and recent activity of Strand B are suggested by a zone of oversteepened and eroding slopes, the northern limit of which is indicated on Plates IIc and IId by a broken line labeled "general change in erosion" (Sections 33-36, T2S, R2E). Although the trough between Strands A and B is only suggested by a subtle bench between Millard Canyon and Lion Canyon, it becomes more pronounced eastward to Stubbe Canyon. Antecedent drainages may have been offset from Stubbe Canyon but show no sign of Holocene displacement. A large (greater than 50 acres) depression north of the Banning Fault Zone, in Section 26, is similar to other topographic depressions north of thrust faults in the Pass and suggests that the northern thrust traces (Strand B ?) have caused backtilting of the leading edge of the upper plate. Ponding of groundwater behind the fault zone is evident, based on anomalous vegetation, in Deep Canyon and at Stubbe Canyon, but there are no obvious scarps across any of the canyons between Millard Canyon and Stubbe Canyon.

Immediately east of Stubbe Canyon Strand B has apparently created a subtle backfacing scarp (in the Holocene (?) alluvium) that passes southeastward into a higher backfacing bedrock scarp. A component of right-lateral slip is suggested by two offset drainages to the east, and this component may also be responsible for the backfacing bedrock scarp at Stubbe Canyon. Further east, to Cottonwood Canyon, the Banning Fault Zone is obscured by landsliding, except where visible in the bedrock exposures southwest of Cottonwood Canyon. Discontinuous scarps at the base of the slope, in the northwest corner of Section 5, are discussed as part of the San Gorgonio Pass Fault Zone (p.11, p.16, p.18).

Cottonwood Canyon to Painted Hill - Plate IId

From Cottonwood Canyon to Painted Hill the Banning Fault Zone is fairly apparent. A spring at Cottonwood Canyon (indicated by trees) marks one high-angle trace of the fault which is additionally defined to the east by aligned linear drainages and ridge and drainage offsets. Oversteepened slopes to the north mark the location of a lower-angle thrust fault which joins the high-angle fault in Section 33. Drainages which cross this thrust are incising upstream and depositing alluvium downstream of the fault. From this point eastward a single fault is marked in general by a linear unnamed canyon, and in detail by numerous linear benches and scarp-like features. The fault is obvious at the Whitewater River where groundwater ponded behind the fault has fed a lush growth of vegetation. East of the Whitewater River a small closed depression was observed in the aerial photos and on the ground, but a field visit also disclosed abundant windblown sand, suggesting that this feature may be aeolian.

<u>Discussion and Conclusions</u> -

Calimesa to Cherry Valley -

There is evidence, both geomorphic and geologic, that a short portion of the Banning Fault, northwest of Cherry Valley, has had Holocene lateral displacement. It is difficult to find any alternate explanation for these features, considering the horizontal striae reported along the near-surface fractures. Indications of recent displacement die out rapidly both eastward and westward. There is no sign of the fault in the Cherry Valley area, but it may have stepped left to the Wildwood Canyon splay.

Wildwood Canyon splay of the Banning fault -

This fault splay, tentatively identified with the Banning Fault Zone, shows no indication of Holocene displacement. Scarps are evident only within pre-Holocene deposits. This fault may have contributed to the height of the Highland Springs scarp.

Cherry Valley to Millard Canyon -

Within this stretch of the fault zone, east of Cherry Valley, there are several traces, recording various stages of activity. The ancestral Banning fault has been reactivated during the early Quaternary. Strand A does not affect the mid-Pleistocene surface of the Banning Bench and therefore is unlikely to have contributed to the Highland Springs scarp since the scarp is younger than the Banning Bench. The fault activity has shifted south in the late Quaternary as the San Gorgonio Pass Fault Zone has developed, but there is evidence that some activity lingered, particularly along Strand B. Strand B crosses the Banning Bench but has no expression in the adjacent eroded crystalline basement rocks. This eroded land is a younger landform than the Banning Bench surface and I would expect the fault to have some remaining expression in the hard crystalline rock if the fault had moved in the Holocene. Banning strand B contributed some height to the Highland Springs scarp. The northwest-trending *en echelon* zone across the Banning Bench may have been part of an early more broadly left-stepping fault zone (along with the Wildwood Canyon splay) which died out as Strand B developed.

Geomorphic expression, although not very sharp within the Beaumont quadrangle, becomes fresher looking as the fault zone steps south and approaches Potrero Creek on the Cabazon quadrangle. This is roughly where the San Andreas Fault would appear to be shunting strain into the various faults of the Pass. Strand A shows no indication of Holocene displacement and is largely modified by erosion or buried by Holocene fan sediments. Strand B is largely a fault-line feature, but looks a little younger where it approaches, and is perhaps influenced by, the San Gorgonio Pass Fault Zone, adjacent to Potrero Creek. The Holocene scarp at Millard Canyon would appear, based on style of faulting (vertical component of displacement), to be related to the Banning Strand B rather than the San Andreas or Gandy Ranch faults, although all of these faults are certainly related.

Millard Canyon to Cottonwood Canyon -

In this segment of the fault zone it appears that the more northerly strands (Strand B?) have been the most recently active. The sense of displacement is somewhat ambiguous in that right-lateral strike-slip appears to predominate at Millard Canyon, yet Deep Canyon and Stubbe Canyon show no sense of lateral offset. Clearly, vertical offset must be more important here. The Strand B faults mark both a distinct change in elevation and a zone where the slopes at this change appear to be oversteepened and actively eroding or sliding. These slope processes suggest localized uplift. Although the fault here is not well-located geomorphically, it has been located on the ground by previous mapping. It has been suggested that some of the mapped faults may actually be the toes of landslides, but I believe that most of the features shown are fault related. Strand A, where it can be differentiated, is generally a fault-line feature which is commonly eroded or buried by younger alluvium.

Cottonwood Canyon to Painted Hill -

The easternmost segment of Strand B, as a north-dipping thrust fault, is reasonably well-defined and appears to affect modern alluvium in several small drainages. The high-angle strike-slip fault which trends east from Cottonwood Canyon is well-defined and is Holocene based on its geomorphic expression as well as historic surface rupture within and east of the study area.

Summary -

In the San Gorgonio Pass the Banning Fault Zone is mostly an older strike-slip structure which has been reactivated in response to local compression. As the Banning Fault exits the Pass to the east it is the main expression of the strike-slip San Andreas Fault Zone. The zone includes the older high-angle Banning Fault (Strand A) and a younger thrust fault (Strand B). Strand B is the more active of the two, and may actually be an early part of the San Gorgonio Pass Fault Zone which is only spatially associated with the Banning Fault. The fault zone is most active from the vicinity of Potrero Creek (where the San Andreas Fault feeds into the system) and eastward into the Coachella Valley. Strain partitioning has probably distributed most of the lateral strain in the Pass along the eastern portion of the Banning Fault (east of Cottonwood Canyon) and then northwest along a deeply buried San Andreas Fault. A minor amount of lateral strain is expressed in the northwest striking tear faults of the San Gorgonio Pass Fault Zone. Some compression is taken up along Strand B of the Banning Fault as well as the thrust faults of the San Gorgonio Pass Fault Zone. Banning Strand A is now largely inactive but might be expected to respond with minor ground rupture where it is influenced by the more recently active faults to its north and south. One anomalous segment with apparent Holocene displacement is west of Cherry Valley where geologic evidence indicates recency.

SAN ANDREAS FAULT (San Bernardino strand)

Previous Work - (Plates Ic & Id)

The San Bernardino strand of the San Andreas Fault has been mapped by various workers within this study area. Vaughan (1922) mapped the San Andreas Fault as a through-going structure, entering the study area through Burro Flats (Cabazon quadrangle), running along the West Branch of Millard Canyon, and coinciding roughly with what is now mapped as the Banning Fault from Lion Canyon eastward. The southeastern portion of Vaughan's San Andreas Fault east of Lion Canyon, is discussed as the Banning Fault (p.20). Rasmussen and Reeder (1986) support the general concept of a through-going San Andreas Fault, but project it a little north of Vaughan's fault. Their trend (not shown on Plates Ic & Id) would take the fault through the West Branch of Millard Canyon, along a fault mapped by Morton and Matti (1993a) in Section 28, and along the south margin of a prominent closed depression at the boundary between the Cabazon and White Water quadrangles (Gary Rasmussen, personal communication, 1993). Rasmussen and Reeder (1986) believe that the San Andreas Fault is obscured through this trend by large-scale landsliding. Their trace meets and truncates the Banning Fault (coming from the west) at Cottonwood Canyon. Recent seismologic evidence (Jones, 1993) suggests that there may be such a throughgoing structure at depth (see p.7), but at the surface this is not evident. A fault trace shown by Dibblee (1981c) through Section 31, west of Cottonwood Canyon (Plate Id) is not shown by others but corresponds to the head area of several landslides mapped by Morton and Matti (1993b).

The clearest surface trace of the San Andreas Fault in the study area is that extending southeastward through Burro Flats toward the mouth of Potrero Creek. This fault trace, along the southwestern margin of Burro Flats, has also been mapped by Allen (1957), Hope (1969), Dibblee (1981b), and Matti and others (1992), but with varying extent (see Plate Ic). None of these, except Dibblee (1981b), portrayed continuity from Burro Flats to the mouth of Potrero Creek. The fault mapping is based principally on geomorphic expression. Dibblee (1981b) shows three traces of the San Andreas Fault in this area: a southwestern trace along the southwest side of the canyon of Potrero Creek, a central trace which is mainly on the northeast side of the canyon, and a northeastern trace which partly follows Vaughan's trace through the West Branch of Millard Canyon but then sweeps south beneath the alluvium of Millard Canyon. Allen mapped parts of each of these traces but did not show the inferred continuity as did Dibblee. Hope mapped only the southwestern trace. Matti and others show only the southwestern trace, but also map a discontinuous, possibly related fault further to the northeast. What would appear to be a southern extension of the San Andreas (on line with Dibblee's trace) is shown by Morton and Matti (1993a) northeast of the mouth of Potrero Creek. This fault is defined by a scarp across the older (but still Holocene) Potrero Creek alluvium (Qyf_2?) and trends southeastward, parallel to and merging with the eastern end of the Gandy Ranch Fault.

Two easterly-trending north-facing scarps have been mapped in the Burro Flats area that are related to the San Andreas Fault (Allen, 1957; Hope, 1969; Matti and others, 1992; Morton and Matti, 1993a). The more southerly of these is a prominent groundwater barrier and was included by Dibblee (1981b) as part of his eastern strand of the San Andreas Fault.

An Earthquake Fault Zone (CDMG, 1974) was established along the San Andreas Fault traces of Allen (1957) and Hope (1969) as well as one of the related east-trending faults at Burro Flats that is a prominent groundwater barrier. (See Plate IIIc for the present zone boundaries).

Aerial Photo Interpretation and Field Observation - (Plate IIc)

The clearest trace of the San Andreas Fault, within this study area, is that which trends southeast along the southwest margin of Burro Flats. This trace is evident both on the ground and in aerial photos as a groundwater barrier and as a long, linear northeast-facing scarp. A prominent north-facing scarp and ponded water and alluvium mark an east-trending splay at the southern margin of Burro Flats, and its eastward extent is suggested by a linear drainage that bounds a low ridge to its south. A more subtle north-facing scarp, shown by Morton and Matti (1993a) is also visible in the field, to the north. This second scarp is more sinuous and is locally breached by very young slopewash. This appears to be an area of very active deposition. The main fault continues southeast along the west margin of the canyon of Potrero Creek. This corresponds to Dibblee's (1981b) southwest trace. It is initially indicated by a scarp or steep linear hillslope and linear drainages but becomes more obscure southward. A small side-valley or basin to the west (in the southeast corner of Section 23) appears to be tectonically dammed. A very low narrow alluvial ridge, which can be seen on the topographic map between the side valley and the main valley is probably fault produced. This ridge is more apparent in the aerial photos where the east side of the ridge is seen to be defined by several minor drainages which each run along the fault for short distances. Southeast of this ridge the San Andreas Fault has probably controlled the linear margin of the canyon. The fault crosses the canyon along a subtle scarp which includes a vague lineation of trees (more apparent on the ground than in aerial photos). This seems to be the same scarp observed by Morton and Matti (1993a). It is within a broader warp which is probably due to the combined effects of the San Andreas Fault and the Gandy Ranch Fault. The fault is more clearly defined to the southeast of Potrero Creek where it has faceted at least two small slopes and then is intermittently expressed by additional faceted slopes and, approaching Millard Canyon, by right-offset ridges and drainages.

Dibblee's (1981b) middle fault trace has no expression along the east side of the Potrero Creek canyon except for, possibly, a small buried bedrock outlier. However, the alluvial surfaces are very young (Qfm and Qyf_5). A linear canyon marks the middle trace as it approaches Millard Canyon, but there are no indications of Holocene activity.

Dibblee's northeast trace is marked by some very general topographic features, including linear slopes and canyons. This fault, and its projection southeast, is basically the trace of Vaughan (1922) as well. Features, such as the West Branch of Millard Canyon, may have developed along an old zone of weakness, but show no indications of recent fault activity. In fact the deflection of Corral Canyon, to the northwest, is *left-lateral*, almost surely indicating that this inferred fault is not involved with modern right-lateral displacement along the San Andreas Fault.

Two parallel faults mapped to the northeast by Morton and Matti (1993a) may also be aligned with the inferred San Andreas Fault trace of Rasmussen and Reeder (1986). The fault segment between Millard and Wood canyons is very weakly defined by some aligned drainages and topographic saddles and a general elevation change. It may also control the head scarp of a landslide. Southeast of Millard Canyon, the second fault segment is also marked by aligned drainages and saddles, as well as a drop in the general landscape elevation. This alignment also includes one right-deflected drainage, however this deflection is not consistently reflected in adjacent canyons or ridges. The most intriguing feature, and the most youthful looking, is a pair of vegetation lineaments across the Holocene alluvium of Millard Canyon at the north edge of Section 29. This pair of lineaments lie close to the projected connection of the two mapped fault segments. To the southeast the through-going fault of Rasmussen and Reeder (1986) is suggested further by a dark tonal band (particularly visible in the various high-altitude photography listed on p.41) that lines up with the Banning Fault east of Cottonwood Canyon. This tonal band corresponds partly with a bench on top of a landslide and also possibly to darker shadows related to the aspect of local slopes.

<u>Discussion and Conclusions</u> -

The San Andreas Fault is the major strike-slip fault dominating the tectonics of southern California in general, and of the San Gorgonio Pass in particular. The San Bernardino strand of the San Andreas Fault is clearly active as it approaches the study area from the north and, based on topography, is a well-defined, Holocene-active fault in the Burro Flats and upper Potrero Creek area. Two active splays, possibly reverse faults, are evident trending eastward across Burro Flats. It has been suggested by various geologists that the surface displacement dies out as the San Andreas Fault approaches the Pass, with the slip transferred to other faults or continuing along a deeply buried San Andreas structure. Subtle geomorphic evidence, as well as the more obvious offsets approaching Millard Canyon suggest that the surface trace of the San Andreas Fault does continue south along Potrero Creek from Burro Flats until it is joined by the Gandy Ranch Fault and then merges with or is truncated by the Banning Fault (Strand B). The various other strands of the San Andreas Fault mapped to the northeast have no indications of Holocene activity or are poorly defined. Inconsistent stream and ridge offsets suggest that these are fault-line features. The large closed depression in the southern part of Section 26 is probably related to the Banning Strand B rather than the San Andreas Fault, as suggested by Rasmussen (personal communication, 1993). Seismic data provides good evidence that there probably is also a straighter, through-going structure at depth which may tie in with the Coachella Valley segment of the Banning Fault.

GANDY RANCH FAULT

Previous Work - (Plates I b & c)

The Gandy Ranch Fault was mapped and named by Allen (1954) based on topographic expression and, near its juncture with the Banning Fault, warping of Quaternary age Heights fanglomerate. Allen also attributed a groundwater barrier and scarp near the mouth of Potrero Creek to this fault (cited by Hope, 1969). Allen notes that at the western end of the fault it does not displace the Heights fanglomerate. An alluvial unit mapped by Dibblee (1981b) in the east branch of Hathaway Creek appears to be offset right-laterally about 500 feet. Morton and Matti (1993a) have mapped some additional detail along this fault as it crosses Potrero Creek and merges to the east with the San Andreas Fault. This includes mapping the scarp of Allen across young alluvium (Qyf_2? and Qyf_5?). The fault is concealed by Qfm. An Alquist-Priolo Earthquake Fault Zone has been previously established around this fault on the Cabazon quadrangle (CDMG, 1974; see Plate IIIc for present zone boundary).

Aerial Photo Interpretation and Field Observation - (Plates II b & c)

Throughout much of its length the fault is marked by the alignment of linear canyons and saddles. The fault-line expression on the Beaumont quadrangle lacks any indication of Holocene displacement. The fault's most youthful expression is east of Potrero Creek (where the fault is marked by truncated and offset ridges) and in the vicinity of Hathaway Creek. The east fork of Hathaway Creek is constricted and the canyon alluvium (Qyf_3?) is uplifted and right-laterally offset north of the fault. The alluvium upstream of the fault appears to be Holocene based on the lack of color development in the soil. A small spring, just north of the mapped fault marks another possible splay. Right-offset ridges occur to the west and east of Hathaway Creek, and to the east of the east fork of Hathaway Creek. However, the modern drainages within the canyons do not appear to be offset. Additional evidence of faulting includes numerous subtle features to the east (see Plate IIc) although the fault is largely obscured until Potrero Creek. Although there is clearly a broad warp at the mouth of Potrero Creek, there is no apparent scarp on line with this fault. A vague, southeast trending southern limit to the trees on the broad scarp may indicate a groundwater barrier. A possible scarp along this trend, observed in the field, may correspond to the more southerly scarp of Morton and Matti (1993a) but it appears to be quite likely the result of lateral erosion of the creek. I could not confirm, either in photos or in the field, the scarp as shown by them. The slightly more prominent scarp just to the north is probably due to the San Andreas Fault. The more youthful-looking fault segment east of Potrero Creek may also be more a product of the San Andreas Fault than the Gandy Ranch Fault.

Discussion and Conclusions -

The Gandy Ranch Fault appears to be principally an older but still slightly active strike-slip fault associated with the San Andreas Fault Zone. At Hathaway Creek it has good evidence of Holocene displacement. Although the modern streams do not show offset, the apparently Holocene alluvium is clearly uplifted and offset laterally. The lack of offset of the younger, incised streams suggests that the last movement on this fault was perhaps mid-Holocene. The fault does not appear to be as active to the west, based on Allen's (1957) observations and the fault's general lack of youthful expression on the Beaumont quadrangle. Youthful expression at Potrero Creek and eastward may be just as likely due to movement on the San Andreas fault, if that fault extends this far south. It is likely that the broad scarp at Potrero Creek is attributable to the combined effects of the Gandy Ranch and the San Andreas Fault.

GARNET HILL FAULT AND RELATED FAULTS ON ALTA MESA

Previous Work - (Plate Id)

The **Garnet Hill Fault** is a right-lateral fault that has been mapped along the southern margin of Alta Mesa, a prominent dissected mesa (that contains the "Whitewater" benchmark) west of the Whitewater River and south of the Banning Fault. It was mapped here by Allen (1957) and Hope (1969) with a left-stepping pattern as shown on Plate 1d. [In some of the literature (Allen, 1954 & 1957) this mesa has been called Whitewater Hill, a name which is now formally used for a different hill about two miles to the southeast.] The fault is inferred along the southern margin of Whitewater Hill (at the quadrangle boundary). The fault was named by Proctor (1968) who discussed the fault (mostly inferred) as it continues east of this study area. Some additional details of fault pattern have come out of more recent mapping by Morton and Matti (1993b) and Rich Wolf (unpublished mapping in progress, CalTech, September 1993). Morton and others (1987) labeled the thrust fault to the southwest as the Garnet Hill Fault, however because of its similarity in fault style to the San Gorgonio Pass Fault Zone (and priority in naming by Smith, 1979) it is here considered to be part of that fault zone (see p.12). I am restricting the Garnet Hill Fault to the strike-slip fault along the southwest side of Alta Mesa. This fault is included within an Alquist-Priolo Earthquake Fault Zone (CDMG, 1980).

Two trenches across a fairly well-defined portion of the western segment of the fault, in the NE corner of Section 9, found evidence for a lack of recent displacement (Rasmussen & Associates, 1984a,b). The trenches exposed massive Cabezon fanglomerate with minor fracturing but no apparent displacement. In one trench the back-facing scarp was mantled with a possible paleosol. Rasmussen observed that the only fault expression consisted of modified scarps in the Quaternary Cabezon fanglomerate, with no expression in younger fan deposits. Another trench in the White Water area failed to find faulting, but was probably south of the fault (Buena Engineers, Inc., 1987). Smith (1979) identified a south-facing scarp along the eastern fault segment near White Water but noted that there was no evidence of Holocene displacement further to the east. The scarp is across what Sieh and Matti (1992) identify as Holocene alluvium.

Minor surface fracturing, possibly indicative of reverse or thrust faulting, occurred along the fault segment near Whitewater Canyon as a result of the 1986 North Palm Springs earthquake (Kahle and others, 1987). Compressional cracks were observed along the south margin of a 10cm wide crack zone along the crest of the pre-existing scarp (E.Hart, personal communication, 1994). Compressional fractures were also observed near the base of the scarp (Sharp and others, 1986). Morton and others (1989) considered the limited rupture to be "a localized surficial response" that did not extend deeper than 100m. Sharp and others (1986) considered the rupture at White Water to be strictly a shaking phenomenon. Sieh and Matti (1992) comment that the aftershock pattern of the North Palm Springs earthquake appears to project upward toward the Garnet Hill Fault.

Several northerly-trending faults and scarp-like features have been mapped across **Alta Mesa**. Some of these faults (from Allen, 1957) are included in the existing Alquist-Priolo Earthquake Fault Zones (CDMG, 1980; see Plate IIId for present zone boundary). Similar, but slightly more extensive faults and scarps were shown by Matti and others (1992; see Figure 3, herein), Morton and Matti (1993b) and Wolf (unpublished mapping in progress, CalTech, September 1993; see Plate Id). The features fall into three sets: a western set along the west side of Section 3, a central set in the middle of the section, and an eastern set in the east part of the section.

The western and central features may veer southeastward into the Garnet Hill Fault (as shown by Matti and others, 1992 and by Wolf; Plate Id). Several of these were investigated by Leighton and Associates (1983) who identified greater extent to some of the previously mapped structures and additional faults outside the Earthquake Fault Zone. They found no evidence to prove or preclude Holocene movement. The trench logs show moderately to steeply-dipping shears (attitudes are shown on Plate Id) with apparent normal separations of as much as 5 feet or more (displacing Cabezon fanglomerate and overlying well-developed soil). The consultant interpreted predominantly strike-slip displacements although they did not explain their evidence or reasoning for this conclusion. [Perhaps they were using an assumed strike-slip model for the faults]. The observed shears displace reddish alluvial or terrace deposits and in some cases may affect the thickness of the uppermost logged soil. Sieh and Matti (1992) estimate that the fanglomerate is older than 500,000-750,000 years old, based on a comparison of the degree of soil development with the work of McFadden (1982). Morton and Matti (1993b) show most of the scarps to be associated with landsliding, although the landsliding may be obscuring faulting as interpreted by Matti and others (1992).

Aerial Photo Interpretation and Field Observation - (Plate IId)

The scarp near White Water is evident in the 1953 USDA aerial photos and is similar to thrust fault scarps elsewhere in this area. A short mapped northwest extension into the hill is very weakly defined by a few subtle discontinuous benches. To the east the fault is suggested by the abrupt southern margin of Whitewater Hill, however this slope is modified by erosion and landsliding.

The *en echelon* strand to the west is not as well defined as the alluvial scarp near White Water. It is also differentiated by topographic features that are more indicative of strike-slip than along the scarp at White Water. These features are discontinuously expressed in the Cabezon fanglomerate but are not visible in the younger, perhaps modern, fans of Cottonwood Creek and other smaller canyons. A brief field reconnaissance along the Garnet Hill Fault could not confirm the fault in limited exposures of coarse conglomerate, but did confirm the more obvious topographic features. Several secondary shears trending N10°W were observed in the Cabezon conglomerate near the mapped fault crossing of the Colorado River Aqueduct.

Numerous scarp-like features are visible across Alta Mesa in the aerial photography. These features may be due to erosion, faulting, landsliding, ridgetop spreading or a combination of these processes. The freshest-looking features, which are probably Holocene in age, are more clearly gravitational in nature. Many of these features coincide with moderate to steeply dipping shears identified during trenching (Leighton and Associates, 1983). Most of the longer mapped lineaments are discontinuous and how they may connect is a matter of interpretation. No field observations were made, for this review, of the various structures across Alta Mesa.

The western set (at the western edge of Section 3) includes a distinct north-south graben across the drainage divide. The fault mapped on the east side of this graben may extend southward along two trends - one on the west side of the ridge and one crossing the ridge. Along the west side of the ridge are two small sidehill benches that may be landslide remnants. They align with two linear drainages to the south that may have eroded along an old landslide margin or fault zone. If the fault crosses the ridge it also changes the direction it faces. It may be that the scarp on the east of the ridge is paired with a more subdued west-facing scarp further east to form another graben. Either of these trends may be enhanced by ridgetop spreading or landsliding and it is difficult to tell if faults are responsible for the modern landform. The southeasterly extension of this zone (after Matti and others, 1992, and Wolf, unpublished mapping in progress, 1993) has no expression across highly eroded and youthful terrain.

The central scarp set, trending southeast form the NW¼ of Section 3, may be largely a result of landsliding and erosion. Two of the elevation breaks, trending southeasterly from the hill crest labeled "Whitewater", appear to be back-facing scarps within a landslide graben. These two surface features were not found to have corresponding shears in trench exposures, but minor shears might not be as evident in the coarse sediments exposed in the trenches. A prominent west-facing scarp that continues southward may be an erosional scarp adjacent to a now largely-eroded inset fan formed during uplift of the mesa. Two southeasterly extensions of this set (south of the aqueduct tunnel) have limited and discontinuous expression. One of these aligns partially with probable landslides. If a fault is present its expression appears to be entirely erosional. The other main scarp in this group faces west and appears to be part of a massive failure complex surrounding the canyon that drains south from the benchmark. This is supported by the concave-south scarps and graben at the north end of this set.

The eastern scarp set appears to be entirely associated with landsliding and ridgetop spreading.

Discussion and Conclusions -

The Garnet Hill Fault is apparently a strike-slip fault related to the Coachella Valley segment of the Banning Fault. The only active (Holocene) portion of the Garnet Hill Fault within this study area is the short alluvial scarp near White Water which may have had minor surface rupture associated with the 1986 North Palm Springs earthquake. Seismicity from this event also suggests that this fault may be active at depth (see p.7). The remainder of the Garnet Hill Fault to the northwest did not show evidence of historic displacement nor of Holocene displacement in trench exposures. It appears to be a result of strike-slip displacement rather than reverse or thrust displacement, and it is not continuous with the active segment to the east, near White Water. It may be that this western segment of the Garnet Hill Fault has been offset by the San Gorgonio Pass Fault. Based on style and strength of expression, it might be reasonable to connect the more clearly active structure at White Water (and eastward) with the San Gorgonio Pass Fault that is similarly expressed about 1km to the west.

The map pattern of faults across **Alta Mesa**, as shown by Matti and others (1992) suggests easterly dipping reverse faults and an east-west compressive environment. In contrast, the westerly set of faults on Alta Mesa appear (based on aerial photo interpretation) to be extensional graben-forming features, perhaps related to rotation of this block between the right-lateral Garnet Hill and Banning faults. The features on Alta Mesa also include more typical arcuate landslides and longer linear scarps and grabens which have resulted from or been accentuated by ridgetop spreading. In any case, the structures across Alta Mesa may include some faults, but are almost certainly dominated by downslope movement resulting from seismic shaking. Where faults have been mapped by others the geomorphic expression on the old surface is not as sharp as the obviously young features that are more clearly associated with ridgetop spreading and landsliding. Subsurface data generally supports landsliding. I conclude that although there are young ground displacements these are probably related to seismic shaking. There is no evidence that the inferred faults across Alta Mesa are active.

****

(blank)

BEAUMONT PLAIN FAULTS

Previous Work - (Plates I a & b)

This group of at least four north-northwest trending normal faults was first identified by Matti and others (1985). The faults (as mapped by Matti and Morton, 1974-91 and 1993; see Plates Ia & Ib) are characterized by mainly northeast-facing scarps in older alluvium (Qdf), although there are a few shorter west-facing scarps. The mapping of Matti and Morton (1974-91 and 1993) portrays the faults as not displacing units as old as Qof. Qof is juxtaposed with Qdf along the fault scarp in a buttress unconformity (J.Matti, personal communication, 1993).

Two of the faults (in Sections 32 and 33) have been investigated by trenching and were interpreted to be pre-Holocene based on scarp-degradation (less than 10° for the more easterly fault and less than 5° for the more westerly fault) and the degree of soil development on the youngest fault-related clastic wedge (Rasmussen & Associates, 1988b).

The McInnes Fault and related faults are probably part of this fault zone and are discussed on p.33.

Aerial Photo Interpretation and Field Observation - (Plates II a & b)

The most prominent fault of this set is the northeasternmost fault, which runs through the town of Beaumont. North of Beaumont the fault is expressed discontinuously but has relatively unbroken expression from Beaumont south. The sharpest scarp along this fault is the west side of a small graben, north of Beaumont (SW¼ Section 34). However, this 10° east-facing scarp is steeper than that on the east side and is probably erosionally enhanced. At both the graben and to the south, drainages crossing the fault become more deeply incised downstream of the fault. In northern Beaumont the fault forms the northeast side of a low ridge rising out of the generally southwest sloping alluvial plain. Further south the fault scarp is up to 2m high with a maximum slope angle of 7°. The scarp was not visible again until south of Beaumont where the fault coincides, in part, with the two traces of the McInnes Fault. An obvious but irregular base of slope marks the fault contact as it angles between the two traces of the McInnes Fault (Section 14). As the fault enters the granitic bedrock along the southwest trace a shear zone is evident in scattered exposures. Fault-line topography is evident, and at the southern margin of the map two northeast-facing scarps mark the location of two fault splays across older alluvium.

To the west, bisecting Section 33, is a short 2-mile long set of scarps in Pleistocene fan deposits (Odf), north of Beaumont. This fault has no expression in younger alluvial units (Ofm and Qw).

The second-longest fault is yet further west (see Section 32 to the west and Section 9 to the south) and has relatively subdued and discontinuous expression. South of Beaumont it may connect to a northwest-trending linear ridge in Section 15 or to a possible fault to the southwest marked by linear drainages and discontinuous scarps in Sections 16 and 22.

The fourth, and western-most fault mapped in this set is visible as two or three west-facing scarps which cross Highway 60 in Sections 5,6, & 8. The eastern scarp (previously unmapped) has a slope angle of less than 5° and the next scarp west has a maximum angle of about 9°. The westernmost mapped scarp is very weakly defined by eroded and subdued scarp remnants. To the southeast features are discontinuous and are interpreted slightly differently than mapped. Linear topographic features and a vegetational lineament mark the possible projection of this fault set along the west side of Mt. Davis. Along the east side of Mt. Davis there is an arcuate west-facing scarp part-way around the mountain. The main trace (?) continues southeast, marked by eroded remnants of a scarp in the old granitic terrain. The general impression of the fault in the granitic terrain is that its expression is controlled by joints or an old shear zone rather than being fault-produced topography. A more prominent, but previously unmapped, alignment of linear drainages and saddles extends southeast from Section 7 (south of Highway 60) through Sections 17 and 21 to Highway 79. This latter lineament shows inconsistent stream deflections and is also likely to be strictly erosional.

An additional strong lineament consisting of aligned linear drainages lies west of and parallel to the previously described fault. No fault has been mapped here, but the erosion has probably been controlled by a zone of joints or shears. There are no geomorphic indicators of recency.

Discussion and Conclusions -

The Beaumont Plain Fault Zone is a northwest-trending extensional zone of faults. It is characterized by several normal faults that are irregularly expressed as scarps in mid-Pleistocene and older surfaces. Two of the four principal strands have been investigated and determined to be pre-Holocene. The longest and best-expressed of the fault strands is probably the same fault as the McInnes Fault to the southeast, a fault which is also not believed to have had Holocene activity. There is no evidence to date to indicate that any of these faults are still active.

****

(blank)

MCINNES FAULT AND RELATED FAULTS OF BLOYD (1971)

Previous Work - (Plate Ib)

This fault was previously evaluated by Smith (1978) and not zoned, but more recent work calls for some re-evaluation of the fault and its relation to the Beaumont Plain faults of Matti and others (1992). As noted by Smith (1978) the name "McInnes Fault" has been applied to two somewhat parallel fault strands. Both of these strands (but only one named) are shown by Bloyd (1971) although he does not discuss the evidence for these faults. A site specific investigation by Stephens (1978) found evidence for faulting in the vicinity of, but not directly on, the northeastern of these two faults south of the town of Beaumont. He dug several trenches across the structure, as defined by resistivity surveys, and found evidence of a north-northwest trending fault zone. Stephens described open fractures along one of the faults that he felt indicated Holocene activity. Smith (1978) judged that the open fractures described by Stephens may be of non-tectonic origin since he could not see any geomorphic evidence to suggest recent displacement along either of the faults as mapped.

Rasmussen & Associates (1985 & 1989b) mapped several fault strands which are associated with the southwestern trace through Section 23. They found that the various strands identified did not cut late-Pleistocene alluvium. They concluded that the geomorphic expression included "highly modified fault scarps, linear drainages and tonal lineaments consistent with older, inactive faulting" and they judged these fault traces to be not active. Blanck (1987) observed that the bedrock appeared to be downdropped to the southwest of the southwestern trace. More recent work by Matti and others (1985 & 1992) has defined the Beaumont Plain Fault Zone. One strand of this zone coincides in part with a part of each of the previously identified strands of the McInnes Fault. The only geomorphic expression to the McInnes faults is where they coincide with the Beaumont Plain Fault strand of Matti and others (1992). The activity and expression of this zone is therefore addressed under the heading of the Beaumont Plain faults (p.31).

Aerial Photo Interpretation and Field Observation - (Plate IIb)

Geomorphic expression coincides, in part, with the northeasternmost strand of the Beaumont Plain Fault Zone and is further discussed on p.31. The remaining portion of the northeastern trace roughly defines a steeper mountain front which may be controlled by a fault or merely a lithologic contact, but has no indication of recency. The southwestern trace likewise has fair expression within the bedrock terrain where it coincides with the northeast strand of the Beaumont Plain Fault Zone, and to the south where there is a short back-facing scarp in Quaternary alluvium. The remaining (northwestern and southeastern) portions of the McInnes Fault of Bloyd (southwestern trace) has little notable expression where it has been previously mapped. There is no discernible geomorphic expression to the fault identified by Stephens (1978), although he observed a very subtle tonal change in the soil which is also visible in the aerial photographs.

Discussion and Conclusions -

The McInnes Fault, as previously mapped, does not have any clear evidence of Holocene faulting. Based on its similar orientation and affinities to the Beaumont Plain faults it, too, is probably an older extensional fault zone. Most likely the two previously mapped strands of the McInnes Fault are merely extrapolated from well-defined segments of the Beaumont Plain Fault Zone (see discussion on p.31). Data presented by Stephens (1978), although suggestive of an active fault, does not belong to a well-defined feature. The observed fractures are probably part of the broader zone of deformation associated with the Beaumont Plain Fault Zone.

"MILLARD CANYON GUARD STATION FAULT"

Previous Work - (Plate Ic)

Allen (1957, p.336) inferred a fault cutting across Millard Canyon near the Millard Canyon Guard Station (Section 21) based on springs which he felt "must be caused by faulting". He observed that "the break is not discernible far east and west of the canyon bottom". Allen's mapping was apparently the basis for one of the original Earthquake Fault Zones established in 1974 (CDMG, 1974). Although Allen (1957) shows this unnamed fault across Quaternary alluvium, it has not been shown by other geologists (for example: Dibblee, 1981b or Matti and others, 1992). The informal name "Millard Canyon Guard Station Fault" is introduced only for the purposes of reference within this report.

Aerial Photo Interpretation and Field Observation - (Plate IIc)

Other than a general northwest orientation to the lower part of the East Branch of Millard Canyon, a short side canyon and a few topographic saddles there is no geomorphic expression to this inferred fault. No indications of late-Quaternary displacement are evident in air photos or in the field.

Discussion and Conclusions -

Based on fault orientation, this is probably an older strike-slip fault. Apparently the only basis for this fault is the presence of springs. This evidence has no bearing on recency of displacement. A comparison of the mapped fault location (CDMG, 1974) with the location of the springs shown on the topographic map shows a poor correspondence. If there is a fault here it is poorly defined and has no evidence for late-Quaternary activity.

****

COX RANCH FAULT

Previous Work - (Plate Id)

This fault was mapped and named by Allen (1954) based on geomorphic evidence and a discontinuity in the foliation of metamorphic rocks. Allen noted that total displacement was probably not great and that there was no evidence of Holocene displacement.

Aerial Photo Interpretation and Field Observation - (Plate IId)

The Cox Ranch Fault is defined by a series of aligned canyons and saddles. The topographic expression appears to be entirely erosional.

No field observations were made.

Discussion and Conclusions -

The topographic expression of the Cox Ranch Fault appears to be entirely a fault-line expression with no evidence of late-Quaternary displacement. Based on orientation, it was probably a strike-slip fault related to the San Andreas Fault Zone.

WHITEWATER FAULT

Previous Work - (Plate Id)

The Whitewater Fault was first mapped by Allen (1954). He described it as "a relatively minor but continuous fault [which] separates crystalline rocks, Coachella fanglomerate, and Quaternary gravels along the east wall of lower Whitewater Canyon" (Allen, 1954, p.128). Allen (1957) shows the fault concealed beneath Cabezon fanglomerate and it is concealed by recent alluvium where it crosses the Whitewater River. Displacement on this steeply to moderately east-dipping fault is relatively up on the east.

Aerial Photo Interpretation and Field Observation - (Plate IId)

The Whitewater Fault is well-expressed by aligned drainages and saddles, however this expression is principally fault-line geomorphology. There is no expression of the fault within the Holocene alluvium.

No field observations were made.

Discussion and Conclusions -

There is no indication of Holocene activity along the Whitewater Fault.

****

SOUTH PASS FAULT

Previous Work -

A fault was postulated by Allen (1954 & 1957) separating the San Jacinto Mountain block from the low-lying pass area. He noted that such a boundary had been proposed by earlier workers as well. Willingham (1981) found that gravity data supported Allen's fault hypothesis. Blanck (1987) applied the name "South Pass Fault" to this structure. This postulated fault would be entirely concealed and may lie along the southern margin of the Pass, but is not depicted on the Plates in this report.

Aerial Photo Interpretation and Field Observation -

The great differences in relief between the San Jacinto Mountains and the San Gorgonio Pass strongly suggest that uplift of the mountains has occurred along a fault boundary. However, the very irregular front with numerous spurs extending out into the Pass suggests that much time has passed since this front was active and erosion has caused somewhat irregular retreat of the mountain front. There are no features indicative of Holocene displacement.

No field observations were made.

Discussion and Conclusions -

Although this inferred fault probably does exist at depth, there is no indication that it is an active fault.

LAWRENCE FAULT, McMULLEN FAULT, RANGER STATION FAULT AND OTHER RELATED STRUCTURES

Previous Work - (Plates I b & c)

These northeast and northwest-trending faults, in the San Jacinto Mountain block at the southern edge of the study area, were shown by Bloyd (1971). The Lawrence Fault was previously shown by Allen (1957) and also later by Matti and Morton (1993) and Morton and Matti (1993a). Morton and Matti show the fault concealed wherever it intersects alluvium, so it is only inferred to displace crystalline basement rock. Bloyd states that many of these faults were mapped and named by the Metropolitan Water District. He does not show any of these faults affecting the water-bearing alluvial deposits. Blanck (1987) extends the McMullen Fault northwest across the pass to coincide with the western margin of the Banning Bench, based on a groundwater barrier. There is nothing in the published literature pertaining to recency or sense of displacement on these faults. Bloyd (1971) inferred one additional unnamed fault extending northwesterly beneath Cabazon and the northeastern part of Banning. This concealed fault is inferred beneath the alluvial deposits of the Pass as a groundwater barrier. It is not mapped into the basement terrain.

Aerial Photo Interpretation and Field Observation - (Plates II b & c)

The northeast-trending Lawrence Fault is well expressed in a gross sense by a series of aligned linear canyons, saddles, and a prominent slope break along the north slope of the San Jacinto Mountains, but the fault trace generally lacks youthful expression except in some bedrock areas where differential erosion has probably enhanced the fault's sharpness. It is intermittently defined, at a finer scale, by side-hill benches and scarps. Differential erosion could be responsible for these features. Neither of these features necessarily indicate recency. Vegetational lineaments along the fault may be due to greater moisture retention and root penetration in a crush or gouge zone. It is covered in at least one stretch by a landslide.

The northwest-trending McMullen Fault is mainly suggested by aligned drainages and saddles. It is well expressed as a pair of faults trending along the northeast and southwest margins of McMullen Flat. The pair of faults are more widely separated at McMullen Flat and step closer together across a northeast trending structure (suggesting vertical offset by the crosscutting fault). Their outcrop pattern suggests a steeply northeast-dipping structure. The fault becomes less well defined north of the Lawrence fault. The inferred northern extension of this fault, as identified by Blanck (1987), is suggested by the orientation of Montgomery Creek and the western margin of the Banning Bench where the fault would coincide with one of the northwest-trending tear faults of the San Gorgonio Pass Fault Zone.

The Ranger Station Fault and other parallel structures may actually be joint controlled rather than fault controlled. The Ranger Station Fault is defined by linear drainages and a prominent adjacent linear ridge, whereas the other parallel faults to the northeast are easier to see in the contours of the topographic map than in the aerial photos. These features show no evidence of Holocene displacement.

The unnamed, concealed fault between Cabazon and Banning has no geomorphic expression in the alluvial deposits or along its projection into the basement terrain.

No field observations were made along any of these faults.

Discussion and Conclusions -

Cross-cutting relationships suggest that the northeast-trending structures may be younger than the northwest-trending structures. Although these faults show abundant indications of their presence, most of these features (aligned drainages and saddles) are probably fault-line features. There is no evidence currently available to suggest that any of these faults are active. Between the general resistance of the granitic rocks of the San Jacinto Mountains and the jointing and old shear zones, prominent lineaments are likely to develop and remain strong long after any tectonic displacement has occurred. The inferred, unnamed fault of Bloyd (1971) between Cabazon and Banning is probably not a real fault. If it were young enough to create a groundwater barrier in the Quaternary alluvial deposits it should be visible in the adjacent bedrock terrain.

MISCELLANEOUS FAULTS PARALLEL TO SAN TIMOTEO CANYON

Previous Work - (Plate Ia)

Several west-northwest trending faults have been mapped within the northern half of the El Casco quadrangle by Shuler (1953) and by Bloyd (1971). The faults mapped by Bloyd (1971) were indicated as hypothetical faults based on water-level, gravity and/or magnetic data. No surface evidence was presented. Two faults were mapped by Shuler (1953), a short northeast dipping fault southwest of San Timoteo Canyon and a steeper, longer fault northeast of the Canyon. The short fault was one of several that Shuler indicated could not be followed for any great distance. The latter fault, which Shuler traced through saddles for nearly two miles, was confirmed as to its existence by subsequent trenching (Dames & Moore, 1987). This fault, which Dames & Moore call the Shadybrook Ranch Fault, was expressed in their Trench 1 as a ½-foot wide zone of fracturing with an attitude of N65°W, 42°N. The fault displaced only Pleistocene San Timoteo Formation and was overlain by young soil. Dames & Moore (1987) investigated other air photo lineaments and concluded that they did not represent active faults, although their trench logs left some doubt about at least one of the lineaments immediately northeast of San Timoteo Canyon Road. Their log of Trench T-7 (T7 on Plate Ia) suggests faulting of both young soil and older colluvium as well as a possible scarp at the ground surface. They stated, however, in their report that there was no faulting at this location and only identified carbonate-coated fractures.

Aerial Photo Interpretation and Field Observation - (Plate IIa)

The longer fault of Shuler (1953) (the Shadybrook Ranch Fault) is marked by some generally aligned drainages and, along its eastern half, it coincides partly with a subtle step in the remains of an old dissected surface. Shuler's shorter fault is not apparent in the topography and shows no signs of recency. Only one of the faults hypothesized by Bloyd (1971) has any expression (aside from the general trend of San Timoteo Canyon). A fault inferred near the northeast side of the canyon coincides with a distinct linear vegetational contrast at the mouth of one of the main side canyons. Further to the southeast, north and south of Highway 60, the inferred fault falls roughly across the end of several spur ridges and with possibly aligned saddles or notches.

Discussion and Conclusions -

The various faults discussed in this section are for the most part very poorly defined. Only one of the faults has been corroborated. They are known or inferred only within the Pleistocene San Timoteo Formation. None of these faults display any evidence of Holocene displacement.

NEOTECTONIC SUMMARY

The San Gorgonio Pass is a region of complex faulting responding principally to the San Andreas Fault system as it accommodates the southern "Big Bend". The principal active strike-slip faults are the right-lateral **San Andreas Fault** (San Bernardino strand) coming into the Pass from the north and the right-lateral Banning Fault (south branch of the San Andreas Fault) entering the pass from the east. The San Andreas is well-defined by scarps in Holocene and late-Pleistocene alluvium where it enters the Pass but becomes obscure within the Pass area itself. The San Andreas Fault may be continuous at depth with the Banning Fault although at the surface this relationship is not evident. This postulated connection sweeps through an otherwise prominent left-step in the surface trace of the fault system. This bend necessitates compression within the pass area.

The **Banning Fault** is an older high-angle strike-slip fault zone which has become reactivated in the Quaternary (Matti and others, 1992). The eastern segment, east of Cottonwood Canyon, is well-defined and remains a dominantly right-lateral fault. This segment offsets Holocene deposits and experienced minor fracturing during the 1986 North Palm Springs earthquake. The rest of the zone, within the Pass, has become dominated by compressional tectonics of the San Gorgonio Pass Fault Zone as the San Bernardino Mountains move southeast along the San Andreas Fault. Although the most active deformation has shifted southward in the Holocene, along the younger strands of the San Gorgonio Pass Fault Zone, some thrust and reverse displacement has probably continued to occur along the ancestral strands of the fault zone that are entwined with the older Banning Fault. There is probably still some component of right-slip along parts of this fault zone.

The **San Gorgonio Pass Fault Zone** is a Quaternary thrust fault system characterized by short prominent thrust segments (in Holocene and late-Pleistocene alluvium) offset by inferred strike-slip "tear faults" (Matti and others, 1992). As interpreted by Matti and others (1992) the earlier strands of this fault zone were superimposed on the older Banning Fault, but the locus of deformation has shifted southward, out from the mountain front. As a low angle thrust the San Gorgonio Pass Fault has probably cut the ancestral Banning Fault at depth to the north. However, due to the presumed north dip of the San Gorgonio Pass Fault Zone it still has some effect on some of the faults in the hanging wall (for example, it's ancestral strands to the north and the faults on Alta Mesa). The youngest faulting is complicated (or obscured) in some parts of the Pass area by large-scale landsliding and probable ridgetop spreading.

Other strike-slip faults in the San Gorgonio Pass, related to the San Andreas and Banning Faults, include the Gandy Ranch Fault and the Garnet Hill Fault. These faults have been active in the Pleistocene, and to some extent also in the Holocene, although they do not appear to now be major tectonic elements of the fault system. There are also older parallel faults to the northeast of the San Andreas Fault which do not seem to be active, although they have been addressed within the body of this report.

Extensional faults include the Beaumont Plain faults and the McInnes Fault. These faults are not well understood (Matti and others, 1992). They have been active in the late Pleistocene, but show no evidence of Holocene activity.

Older faults in the Pass, such as the Whitewater River Fault, South Pass Fault, Lawrence Fault, McMullen Fault, and Ranger Station Fault as well as miscellaneous faults in San Timoteo Badlands show no evidence of late-quaternary activity and do not appear to be related to the current tectonic mechanisms.

Various studies within the region have postulated late-Quaternary or Holocene slip-rates for the San Andreas Fault of 25mm/yr north of Redlands (Rasmussen, 1982) diminishing to 6-25mm/yr less than 15km northwest of where the fault enters the study area (Harden and Matti, 1989). This diminution of slip-rate may be accommodated by the extensional faults of the Crafton Hills Fault Zone and by the San Jacinto Fault zone to the west. A historic creep rate of 2mm/yr has been interpreted on the Banning Fault a few kilometers east of the study area (Allen and Sieh, 1983). Slip-rates (compressional) for the San Gorgonio Pass Fault Zone inferred in this report indicate a late-Quaternary vertical slip-rate of 0.9-1.6mm/yr near Banning and as high as 2.6-3.6mm/yr near Cabezon. This latter figure, however, is not supported by the youngest displacement which only documents a late-Holocene slip rate of 0.3mm/yr. Matti and others (1992, p.26) suggest that the San Gorgonio Pass Fault Zone "may be spatially and temporally cyclic". The faults in the Pass generally show more evidence of activity in the eastern half of the study area, reflecting the stress input from the San Andreas Fault Zone.

RECOMMENDATIONS FOR ZONING
(Plates III a, b, c & d)

San Gorgonio Pass Fault Zone

The San Gorgonio Pass Fault Zone (including the Cherry Valley Fault) is not sufficiently active west of the Banning Bench to be included in an Earthquake Fault Zone, and the northwest-trending fault along the west side of the Banning Bench is also poorly defined. Along the southern margin of the Banning Bench and eastward the fault zone is locally well-defined and displaces Holocene deposits. From Section 5 in Banning and eastward to Cottonwood Canyon, as shown on Plates IIIb, c and d, this fault zone should be included in a new Earthquake Fault Zone, incorporating the existing zone segment on Plate IIIc. The existing Earthquake Fault Zone along this fault in the east half of the White Water quadrangle (Plate IIId) should be retained and extended to the quadrangle boundary to include the concealed fault south of Whitewater Hill (Garnet Hill Fault ?). The northeast-trending fault south of Cottonwood Canyon (in Section 5) appears to affect Holocene deposits and should also be included in an Earthquake Fault Zone. A northwest-trending fault in Section 1 on the west half of the White Water quadrangle (shown on Plate Id) that is currently zoned has no evidence for Holocene activity and its Earthquake Fault Zone should be deleted.

Zoning to be based on fault traces of Kahle and others (1987), Matti and others (1992, as modified by Matti and Morton (1993), Morton and Matti (1993a,b)), Smith (1979), and this Fault Evaluation Report.

Banning Fault Zone

The fault segment west of Cherry Valley shown on Plate IIIa is well-defined and shows both geomorphic and geologic evidence for Holocene displacement. It should be incorporated into a new Earthquake Fault Zone. The Wildwood Canyon splay, as well as various splays across the Banning Bench (Strands A and B, Plates Ib & Ic), although well-defined, show no evidence of Holocene displacement and should not be zoned. On the Cabazon and White Water quadrangles (Plates IIIc and IIId) the northern strand (Strand B) should be retained in a modified Earthquake Fault Zone (including east of Cottonwood Canyon) and extended just west of Potrero Creek based on moderately fresh geomorphic expression. The southern strand (Strand A) shows no evidence of Holocene activity and should be deleted from its existing Earthquake Fault Zone. The location used for Strand B between Millard Canyon and Cottonwood Canyon is based on the mapping of Morton and Matti (1993a & 1993b). The well-defined high-angle fault eastward from Cottonwood Canyon has good geomorphic expression indicating recent displacement and should be retained in an Earthquake Fault Zone.

Zoning to be based on fault traces of Clark (1984), Hope (1969), Matti and others (1992, as modified by Matti and Morton (1974-91) and Morton and Matti (1993a,b)), Woodward-Clyde Consultants (1993), and this Fault Evaluation Report.

San Andreas Fault

The San Andreas Fault, as shown on Plate IIIc, is well defined for most of its length and has geomorphic and geologic indications of Holocene activity. The existing Earthquake Fault Zone for the San Andreas Fault at Potrero Creek should be modified and extended southward to its juncture with the Gandy Ranch Fault. The existing Earthquake Fault Zone trending east toward Wood Canyon should also be revised to reflect the narrower zoning practiced since 1977 (Hart, 1994). The subparallel fault to the north (Section 14) displaces Holocene deposits and should be included in a new Earthquake Fault Zone. The central branch of Dibblee (1981b) has no indication of Holocene displacement and its Earthquake Fault Zone should be withdrawn. The other parallel fault branches to the northeast similarly have no evidence of Holocene activity and should not be zoned.

Zoning to be based on fault traces of Hope (1969), Matti and others (1992, as modified by Morton and Matti (1993a)), and this Fault Evaluation Report.

Gandy Ranch Fault

The fault, as shown on Plate IIIc, appears sufficiently active and well-defined at least as far west as Hathaway Creek and should be retained in an Earthquake Fault Zone. To the west, on the Beaumont quadrangle, the fault is not as well-defined, is not sufficiently active and should not be zoned. The fault segment east of Potrero Creek is active (regardless of its affinity to the Gandy Ranch or San Andreas fault) and should also be retained in an Earthquake Fault Zone. The current zone boundaries should be modernized to reflect the narrower zoning practiced since 1977 (Hart, 1994).

Zoning to be based on fault trace of Matti and others (1992, as modified by Morton and Matti (1993a)) and this Fault Evaluation Report.

Garnet Hill Fault and related faults on Alta Mesa

The Garnet Hill Fault is moderately well to well defined but, except near White Water (San Gorgonio Pass Fault Zone ?), it has no evidence of Holocene displacement. Where the fault crosses the Whitewater River, forming a scarp in Holocene alluvium, it should remain in an Earthquake Fault Zone that should be connected to the San Gorgonio Pass Fault to the west. This zone should be extended to the eastern boundary of the quadrangle to include the inferred trace south of Whitewater Hill. The western strand of the Garnet Hill Fault is a Pleistocene strike-slip fault with some data to indicate no Holocene activity. Consequently its Earthquake Fault Zone should be withdrawn.

The observable features across Alta Mesa are almost entirely gravitational in origin. Although there is no evidence of active faulting, any of the observed features can be expected to respond to a ground rupture event along either the San Gorgonio Pass or Banning faults. The potential for seismically induced landsliding and lateral spreading should be noted across Alta Mesa on the Official Earthquake Fault Zone map. Current Earthquake Fault Zones on the top of Alta Mesa (other than those for the Banning Fault) should be deleted.

Zoning to be based on fault trace of Hope (1969), Matti and others (1992, as modified by Morton and Matti (1993b)) and this Fault Evaluation Report.

Beaumont Plain faults

Although reasonably well-defined, the faults of this zone are not sufficiently active and no Earthquake Fault Zone is recommended.

McInnes Fault

This fault has no indication of Holocene displacement and no Earthquake Fault Zones are recommended.

"Millard Canyon Guard Station Fault"

This fault is poorly defined and has no evidence of Holocene displacement. The existing Earthquake Fault Zone for this fault on the Cabazon quadrangle should be withdrawn.

Cox Ranch Fault

This fault has no indication of Holocene displacement and no Earthquake Fault Zones are recommended.

Whitewater River Fault

This fault has no indication of Holocene displacement and no Earthquake Fault Zones are recommended.

South Pass Fault

This fault has no indication of Holocene displacement and no Earthquake Fault Zones are recommended.

Lawrence Fault, McMullen Fault, Ranger Station Fault and related structures

None of these faults have evidence of Holocene displacement and no Earthquake Fault Zones are recommended.

Miscellaneous faults parallel to San Timoteo Canyon

No Earthquake Fault Zones are recommended along any of the faults discussed.

Jerome A. Treiman

Jerome A.Treiman
Associate Geologist
EG 1035

Reviewed, recommendations approved. Earl W. Hart
Sen. Geol.
CEG 935
10/4/94

AERIAL PHOTOGRAPHS USED

U.S. Department of Agriculture

	scale - 1:20,000		b/w	9x9
frames	AXM - 1K - 99 to 107	8/22/53		
	114 to 122	8/22/53		
	196 to 208	8/27/53		
	AXM - 4K - 24 to 33	10/20/53		
	89 to 99	10/20/53		
	AXM - 8K - 46 to 52	10/21/53		
	60 to 67	10/21/53		
	133 to 139	10/21/53		
	142 to 148	10/21/53		
	AXM -12K - 36 to 44	11/25/53		
	53 to 60	11/25/53		
	126 to 133	11/25/53		
	141 to 147	11/25/53		
	AXM -13K - 169 to 175	12/06/53		
	AXM -15K - 95 to 104	12/31/53		

Fairchild Aerial Surveys

flight C4058 — 6/08/36
scale - 1:18,900 — b/w — 7x9
frames 1 to 41
50 to 84

flight 24244 — 1/29/62
scale - 1:24,000 — b/w — 9x9
frames 2-216 to 2-221
2-224 to 2-230
2-256 to 2-262
2-269 to 2-273
2-300 to 2-305
2-310 to 2-315
3-345 to 3-350

Riverside County Flood Control District

8/30/58	1:12,000	b/w	9x9:	frames 31 to 33 & 37 to 44
10/15/58	1:12,000	b/w	9x9:	frames A28-A36 & A41-A43
12/19/58	1:12,000	b/w	9x9:	frames 11 to 15
1/30/61	1:12,000	b/w	9x9:	frames 31 to 53
6/16/61	1:6,000	b/w	9x9:	frames 51 to 58
5/24/74	1:24,000	b/w	9x9:	frames 28 to 47, 103 to 122, & 177 to 192

NASA

U-2 flight 72-112 — scale - 1:130,000 — color-IR — 9x9
frames 2770 & 2771 — 7/11/72

USAF

scale - 1"= approx. 2 miles — b/w — 9x9
Flight 059v — frames 128-130 — 7/17/68
Flight 064v — frames 171-174 — 7/18/68

REFERENCES

(* - unpublished consultants reports: [AP#] or [C#] designation indicates report is on file with CDMG; [GR#] indicates report is on file with Riverside County)

Allen, C.R., 1954, The San Andreas Fault Zone in San Gorgonio Pass, California: unpublished PhD thesis, California Institute of Technology, 147p.

Allen, C.R., 1957, San Andreas Fault Zone in San Gorgonio Pass, southern California: Geological Society of America Bulletin, v.68, p.315-350.

Allen, C.R., and Sieh, K.E., 1983, Creep and strain studies in southern California *in* Jacobson, M.L., ed., Summaries of technical reports, volume XVII: U.S. Geological Survey Open-File Report 83-918, p.199-202.

Blanck, E.L., 1987, Geologic structure of the Beaumont-Banning area, California, from gravity profiles: unpublished MS thesis, California State University, Los Angeles, 201p.

Bloyd, R.M., Jr., 1971, Underground storage of imported water in the San Gorgonio Pass area, southern California: U.S. Geological Survey Water-Supply Paper 1999-D, 37p.

* Buena Engineers, Inc., 1987, Geologic hazards report, Whitewater Rock & Supply Company, Whitewater, Riverside County, California: unpublished consultant's report, Project No. B-7388-V01 / 87-6-97, June 10, 1987. [GR422; AP151]

CDMG, 1974, Official map of Special Studies Zones, Cabazon quadrangle: California Division of Mines and Geology, July 1, 1974, 1:24,000.

CDMG, 1980, Revised official map of Special Studies Zones, Whitewater quadrangle: California Division of Mines and Geology, revised January 1, 1980, 1:24,000.

CDMG, 1988, Revised official map of Special Studies Zones, El Casco quadrangle: California Division of Mines and Geology, revised March 1, 1988, 1:24,000.

Clark, M.M., 1984, Map showing recently active breaks along the San Andreas Fault and associated faults between Salton Sea and Whitewater River-Mission Creek, California: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1483, 1:24,000.

* Clopine Geological Services, 1988, Geologic trenching report, 30-acre site, northwest of Millard Pass Road and Seminole Drive, vicinity of Cabazon, Riverside County, California: unpublished consultant's report, June 14, 1988. [GR542; AP2194]

* Clopine Geological Services, 1989a, Fault investigation for proposed 1.5 million gallon water reservoir, northeast quarter of the northeast quarter, section 7, T3S, R2E, SBB&M, Cabazon area, Riverside County, California: unpublished consultant's report, February 20, 1989. [GR714; AP2390]

* Clopine Geological Services, 1989b, Geological evaluation, tentative parcel map No. 24456, Calimesa area, Riverside Co., California: unpublished consultant's report, June 14, 1989. [GR636] *GR636 - no fault in trenches*

* Clopine Geological Services, 1989c, Geologic/seismic report for 20 acre (±) parcel in the northeast quarter of the northwest quarter, section 7, T3S, R2E, SBB&M, Cabazon area, Riverside County, California: unpublished consultant's report, June 14, 1989. [GR741; AP2440]

* Clopine Geological Services, 1990, Addendum to geologic/seismic report for 20 acre (±) parcel in the northeast quarter of the northwest quarter, section 7, T3S, R2E, SBB&M, Cabazon area, Riverside County, California: unpublished consultant's report, August 10. 1990. [GR741; AP2440]

* Dames & Moore, 1987, Geology and seismicity, Oak Valley, Riverside County, California: unpublished consultant's report included as Part V, Technical Appendix A of EIR for the title project, proj. no. 42.OG/3, Nov.17, 1987.

Dibblee, T.W., Jr., 1957-58, unpublished mapping of the Banning and Palm Springs 15-minute quadrangles (maps on file with CDMG Regional Mapping Program) [subsequently published maps (Dibblee, 1981 b & c) show slightly different, and more complete, mapping]

Dibblee, T.W., Jr., 1975, Late Quaternary uplift of the San Bernardino Mountains on the San Andreas and related faults *in* Crowell, J.C., ed., San Andreas Fault in southern California, a guide to San Andreas Fault from Mexico to Carrizo Plain: California Division of Mines and Geology, Special Report 118, p.127-135.

Dibblee, T.W., Jr., 1981a, Geologic map of the Perris (15 minute) quadrangle, California: South Coast Geological Society, Geologic Map SCGS-1, 1:62,500.

Dibblee, T.W., Jr., 1981b, Geologic map of the Banning (15 minute) quadrangle, California: South Coast Geological Society, Geologic Map SCGS-2, 1:62,500.

Dibblee, T.W., Jr., 1981c, Geologic map of the Palm Springs (15 minute) quadrangle, California: South Coast Geological Society, Geologic Map SCGS-3, 1:62,500.

Harden, and Matti, 1989, Holocene and late Pleistocene slip rates on the San Andreas fault in Yucaipa, California, using displaced alluvial-fan deposits and soil chronology: Geological Society of America Bulletin, v.101, p.1107-1117.

Hart, E.W., 1983, unpublished letter to Mr. Anthony Brown, Engineering Geologist, Riverside County Planning Department, acknowledging receipt of report by Lohr (1983): California Division of Mines and Geology, October 13, 1983. [part of file AP1563]

Hart, E.W., 1994, Fault-rupture hazard zones in California: California Department of Conservation, Division of Mines and Geology Special Publication 42, Revised 1994, 34p.

Hill, R.T., 1928, Southern California geology and Los Angeles earthquakes: Southern California Academy of Sciences, Los Angeles, 232p.

Hope, R.A., 1969, Map showing recently active breaks along the San Andreas and related faults between Cajon Pass and Salton Sea, California: U.S. Geological Survey Open File Map, 1:24,000.

* ICG, Inc., 1990, Fault hazard/landslide evaluation and preliminary geotechnical investigation, 242± acres residential development, NEC Cherry Valley Blv. and Roberts Ave., Riverside County, California: unpublished consultant's report, Job No.07-7939-002-00-00, 1/2/90. [GR688]

Jennings, C.W., 1992, Preliminary fault activity map of California: California Department of Conservation, Division of Mines and Geology Open-File Report 92-03, 1:750,000.

Jones, L.M., Hauksson, E., and Qian, H., 1993, (abst.) Where is the San Andreas Fault in the San Bernardino Mountains of southern California?: Seismological Research Letters, v.64, no.1, p.22.

Jones, L.M., Hutton, L.K., Given, D.D., and Allen, C.R., 1986, The North Palm Springs, California, earthquake sequence of July 1986: Bulletin of the Seismological Society of America, v.76, no.6, p.1830-1837.

Kahle, J.E., 1987, The San Jacinto Fault Zone (the Claremont, Casa Loma, and related faults) in the Lakeview and El Casco quadrangles, Riverside County, California: California Division of Mines and Geology, unpublished Fault Evaluation Report FER-179, Final Draft July 21, 1987, 9p.

Kahle, J.E., Hart, E.W., Borchardt, G., and Manson, M.W., 1987, Surface rupture associated with the North Palm Springs earthquake of July 8, 1986 -- Banning and related faults, Riverside County: unpublished Fault Evaluation Report FER-185, California Division of Mines and Geology, August 7, 1987, 15p.

* Leighton and Associates, 1983, Preliminary geotechnical investigation, Alta Mesa, section 3, T3S, R3E, Whitewater, Riverside County, California: unpublished consultant's report, Project No. 6830028-03, February 15, 1983. [AP1723]

* Lohr, L.L., 1983, Fault hazard report for a wind turbine site lying within a portion of the north half of section 9, T3S, R3E, SBB&M, Riverside County, California: unpublished consultant's report, Job No. 110-83-8, August 12, 1983. [AP1563]

Matti, J.C., and Morton, D.M., 1982, (abstract), Geologic history of the Banning Fault Zone, southern California: Geological Society of America, cordilleran Section Meeting, Abstracts With Programs, v.14, no.4, p.184.

Matti, J.C., and Morton, D.M., 1974-91 (in preparation), Geologic map of the El Casco 7.5' quadrangle, Riverside County, California: U.S.Geological Survey, unpublished mapping, 1:24,000.

Matti, J.C., and Morton, D.M., 1993 (in preparation), Geologic map of the Beaumont 7.5' quadrangle, Riverside County, California: U.S.Geological Survey, unpublished mapping, 1:24,000.

Matti, J.C., Morton, D.M., and Cox, B.F., 1985, Distribution and geologic relations of fault systems in the vicinity of the Central Transverse Ranges, southern California: U.S. Geological Survey, Open-file Report 85-365, 27p.

Matti, J.C., Morton, D.M., and Cox, B.F., 1992, The San Andreas Fault system in the vicinity of the central Transverse Ranges Province, southern California: U.S. Geological Survey Open-File Report 92-354, 50p., map scale - 1:250,000.

Matti, J.C., Tinsley, J.C., Morton, D.M., and McFadden, L.D., 1982, Holocene faulting history as recorded by alluvial stratigraphy within the Cucamonga fault zone: a preliminary view *in* Tinsley, J.C., Matti, J.C., and McFadden, L.D., Guidebook: Late Quaternary pedogenesis and alluvial chronologies of the Los Angeles and San Gabriel Mountains areas, southern California and Holocene faulting and alluvial stratigraphy within the Cucamonga fault zone: a preliminary view: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Field Trip Number 12 Guidebook, p.29-44.

McFadden, L. D., 1982, The impacts of temporal and spatial climatic changes on alluvial soils genesis in southern California: unpublished PhD thesis, University of Arizona, 430p.

* Medall, Aragon, Warsick & Assoc., Inc., 1979, Geologic investigation of faulting, tentative tract no. 10777, south of Wildwood Canyon, Yucaipa, California: unpublished consultant's report, Project No. 1463, May 14, 1979.

Morton, D.M., Campbell, R.H., Jibson, R.W., Wesson, R.L., and Nicholson, C., 1989, *in* Sadler, P.M., and Morton, D.M., Landslides in a semi-arid environment with emphasis on the inland valleys of southern California: Publications of the Inland Geological Society, Volume 2, p.183-196.

Morton, D.M., and Matti, J.C., 1993a (in preparation), Geologic map of the Cabazon 7.5' quadrangle, Riverside County, California: U.S.Geological Survey, unpublished mapping, 1:24,000.

Morton, D.M., and Matti, J.C., 1993b (in preparation), Geologic map of the Whitewater 7.5' quadrangle, Riverside County, California: U.S.Geological Survey, unpublished mapping, 1:24,000.

Morton, D.M., Matti, J.C., and Tinsley, J.C., 1987, Banning Fault, Cottonwood Canyon, San Gorgonio Pass, southern California *in* Hill, M.L., ed., Centennial Field Guide, Volume I -- Cordilleran Section of the Geological Society of America: Geological Society of America, p.191-192.

Proctor, R.J., 1968, Geology of the Desert Hot Springs-upper Coachella Valley area, California: California Division of Mines and Geology, Special Report 94, 50p.

Rasmussen, G.S., 1982, Geologic features and rate of movement along the south branch of the San Andreas fault, San Bernardino, California *in* Cooper, J.D., comp., Neotectonics in southern California: Geological Society of America, Volume and Guidebook, Cordilleran Section, 78th Annual Meeting, Anaheim, California, April 19-21, 1982, p.109-114.

* Rasmussen, G.S., & Associates, 1979a, Geology investigation, 240-acre mobile home park, environmental impact report, east of Sunset Avenue, approximately 1,000 feet north of Wilson Street, a portion of T3S,R1E, sec.5, Banning, California: unpublished consultant's report, Project No. 1542, September 19, 1979.

* Rasmussen, G.S., & Associates, 1979b, Geology investigation, 350-acre site, environmental impact report, east of Sunset Avenue, approximately 1 mile north of Wilson St, Banning, California: unpublished consultant's report, Project No. 1542-2, November 27, 1979.

* Rasmussen, G.S., & Associates, 1983, Preliminary engineering geology investigation of the proposed 1,350-acre Canyon Oaks development, west of County Line Road, San Bernardino and Riverside counties, Calimesa, California: unpublished consultant's report, Project No. 1789, December 22, 1983. [GR242; C819]

* Rasmussen, G.S., & Associates, 1984a, Preliminary engineering geology investigation of proposed wind energy project, portion of sections 5 and 9, T2S, R3E, SBB&M, west of Alta Mesa, San Gorgonio Pass, Riverside County, California: unpublished consultant's report, Project No. 2016, May 14, 1984. [GR303; C820]

* Rasmussen, G.S., & Associates, 1984b, Addendum to our preliminary engineering geology investigation of proposed wind energy project, San Gorgonio Pass, Riverside County, California: unpublished consultant's report, Project No. 2016-2, June 28, 1984. [GR303; C820]

* Rasmussen, G.S., & Associates, 1985, Preliminary engineering geology investigation of the Futura Valley Farms project, approximately 737 acres, section 23 and S¼ of section 24, T3S, R1W, SBB&M, Beaumont California: unpublished consultant's report, Project No. 2109, February 4, 1985.

* Rasmussen, G.S., & Associates, 1987, Subsurface engineering geology investigation, proposed single family residence, parcel 2, tentative parcel map 22601, south of Buena Mesa Drive, east of Mesa Grande Drive, Calimesa, California: unpublished consultant's report, Project No. 2416.1, December 8, 1987. [GR504]

* Rasmussen, G.S., & Associates, 1988a, Geologic evaluation of the proposed reservoir site for tract no. 10931, within the S½ of the SW¼ of the NE¼, section 16, T2S, R1W, Wildwood Canyon area, east of Yucaipa, California: unpublished consultant's report, Project No. 2128.11, March 16, 1988. [GR522]

* Rasmussen, G.S., & Associates, 1988b, Engineering geology investigation of faulting, Oak Valley project, northern Riverside County, California: unpublished consultant's report Project No. 2529.5, October 20, 1988. [GR464 update; C691]

* Rasmussen, G.S., & Associates, 1989a, Subsurface engineering geology investigation, Tentative Tract No. 23598, lots 1-99, northeast of Sunrise Avenue and Wilson Street, Banning, California: unpublished consultant's report, Project No. 2680, July 27, 1989. [C822]

* Rasmussen, G.S., & Associates, 1989b, Subsurface engineering geology investigation, Potrero Creek Estates, approximately 737 acres, Beaumont, California: unpublished consultant's report, Project No. 2109.2, October 25, 1989.

* Rasmussen, G.S., & Associates, 1990, Engineering geology investigation, tentative tract no,25151 within the E½ of the SE¼ of section 13, T2S, R2W, SBB&M, Calimesa, California: unpublished consultant's report, Project No. 2854, March 6, 1990. [GR670 update]

* Rasmussen, G.S., & Associates, 1992, Subsurface engineering geology investigation , 10258 Jonathan Avenue, Cherry Valley, California: unpublished consultant's report, Project No. 2962.1, April 7, 1992. [C823]

* Rasmussen, G.S., & Associates, 1994, Subsurface engineering geology investigation, approx. 50 acres east of Fields Road between Seminole Dr. and Martin Road, Cabazon area, California: unpublished consultant's report, Project No. 3188, March 14, 1994. [GR877]

Rasmussen, G.S., and Reeder, W.A., 1986, What happens to the real San Andreas Fault at Cottonwood Canyon, San Gorgonio Pass, California? *in* Kooser, M.A., and Reynolds, R.E., eds., Geology around the margins of the eastern San Bernardino Mountains: Publications of the Inland Geological Society, Volume I, May 1986, p.57-62.

* Rockwell, T., 1993, letter report to Woodward-Clyde Consultants dated 15 January, 1993: included as Appendix A in Woodward-Clyde Consultants (1993), 3p.

* Schaefer Dixon Associates, 1990 (revised), Evaluation of the Banning Fault between California and Bryant streets and south of Myrtlewood Drive., Calimesa, Riverside County, California: unpublished consultant's report, Job No. 9R-075B, July 12, 1989, revised January 10, 1990. [GR670]

Sharp, R.V., Rymer, M.J., and Morton, D.M., 1986, Trace-fractures on the Banning Fault created in association with the 1986 North Palm Springs earthquake: Bulletin of the Seismological Society of America, v.76, no.6, p.1838-1843.

Shuler, E.H., 1953, Geology of a portion of the San Timoteo Canyon badlands near Beaumont, California: unpublished M.S. thesis, University of Southern California, 106p.

Sieh,K., and Matti, J.C., 1992, The San Andreas fault system between Palm Springs and Palmdale, southern California: field trip guidebook *in* Sieh K.E., and Matti J.C., leaders, Earthquake geology, San Andreas fault system, Palm Springs to Palmdale: Southern California Section, Association of Engineering Geologists, Guidebook and Reprint Volume, prepared for the 35th Annual Meeting, Long Beach, California, Oct.2-9, 1992, p.1-12.

* Smith, C., 1988, Geotechnical investigation report, tentative parcel map 22405, SW ¼, section 19, T2S, R1W, SBB&M, Calimesa, California: unpublished consultant's report, Job No. 87-42G, January 24, 1988. [GR491; C821]

Smith, D.P., 1978, The McInnes Fault: California Division of Mines and Geology, unpublished Fault Evaluation Report FER-79, 6p.

Smith, D.P., 1979, San Gorgonio Pass Fault: California Division of Mines and Geology, unpublished Fault Evaluation Report FER-87, 7p.

* Soil and Testing Engineers, Inc., 1986, Alquist-Priolo geotechnical study for the northern one-half of section 1, T3S, R3E, SBB&M, located north of Highway 10 and west of Painted Hills, Riverside County, California: unpublished consultant's report, September 23, 1986. [GR406; C640]

* Stephens, E.E., 1978, Subsurface exploration (geophysical and trenching) in the vicinity of the proposed Beaumont Avenue railroad grade separation: unpublished report, California Department of Transportation, April 3, 1978. [C289]

Vaughan, F.E., , 1922, Geology of San Bernardino Mountains north of San Gorgonio Pass: University of California Publications, Bulletin of the Department of Geological Sciences, v.13, no.9, p.319-411.

Willingham, R.C., 1981, Gravity anomaly patterns and fault interpretations in the San Bernardino Valley and western San Gorgonio Pass area, southern California *in* Brown, A.R., and Ruff, R.W., eds., Geology of the San Jacinto Mountains: South Coast Geological Society, Annual Field Trip Guidebook No. 9, p.164-174.

* Woodward-Clyde Consultants, 1993, Feasibility-level geologic/geotechnical investigations for Upper Singleton Canyon Reservoir, Riverside County, California: unpublished consultant's report, project no. 924G094A, April 1993. [C824]